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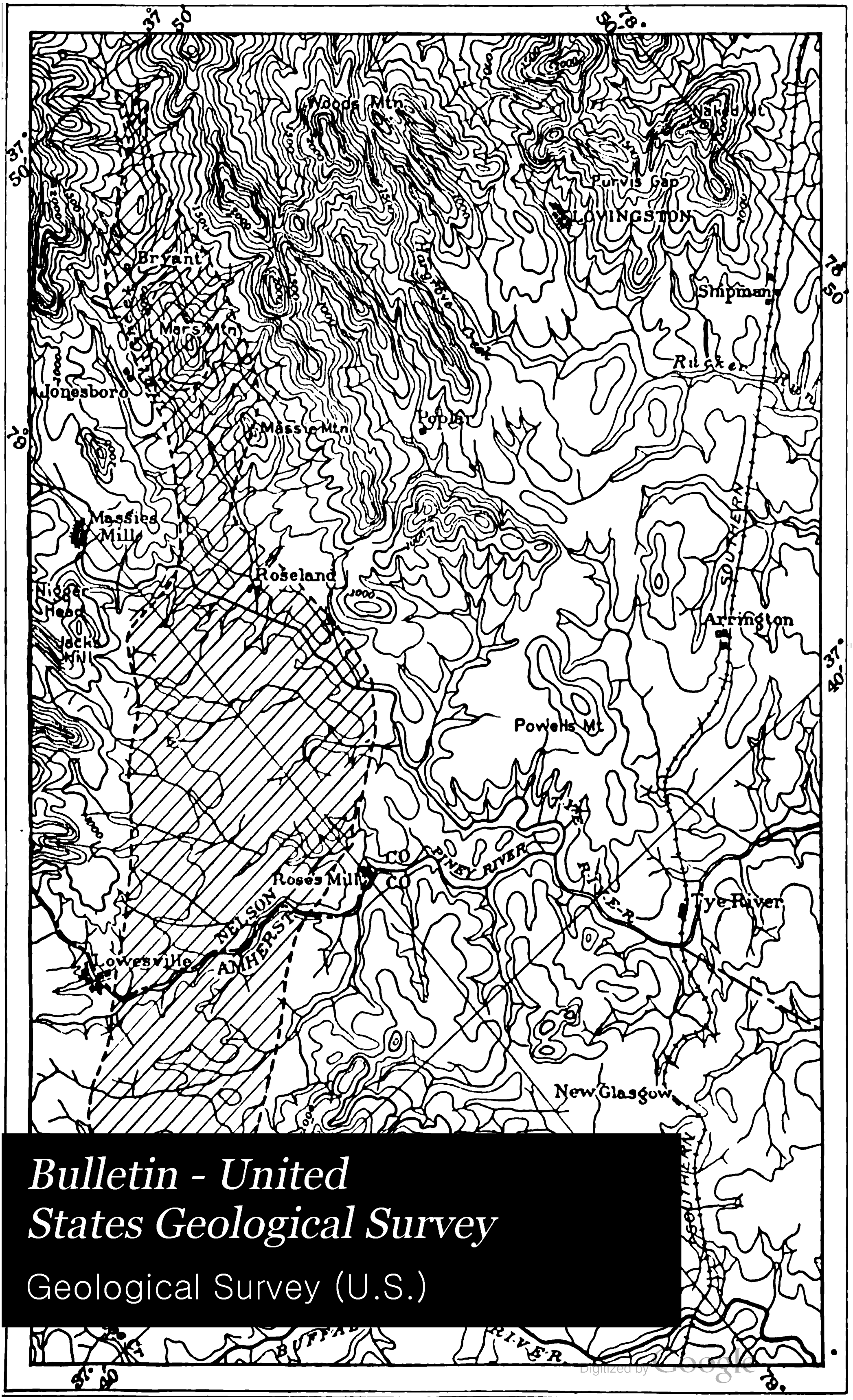

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GEORGE OTIS SMITH, DIRECTOR

BULLETIN 580—A

THE
DARWIN SILVER-LEAD MINING DISTRICT
CALIFORNIA

BY

ADOLPH KNOPF

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CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1913, PART I—A

WASHINGTON
GOVERNMENT PRINTING OFFICE
1914

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
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THE DARWIN SILVER-LEAD MINING DISTRICT, CALIFORNIA.

By ADOLPH KNOPF.

INTRODUCTION.

Most of the lead ore produced in California has come from the Cerro Gordo, Darwin, and Modoc districts, all in Inyo County, in the eastern part of the State. The Cerro Gordo district has been by far the most productive, having yielded during its most prosperous years $7,000,000 in argentiferous lead. The Darwin district has probably yielded between $2,000,000 and $3,000,000.

The geologic features of the Cerro Gordo district have recently been described by the writer,[1] and it is the purpose of the present report to describe those of the Darwin district. The data on which this report is based were obtained during the period from May 11 to May 19, 1913.

Some notes on the district have been given by W. A. Goodyear[2] and brief reference has been made to it by H. W. Fairbanks.[3]

GEOGRAPHY.

Darwin is situated in Inyo County, Cal., 24 miles southeast of Keeler, the southern terminus of the Nevada & California Railroad. It is a small settlement which in 1913 contained but a score or two of inhabitants. It lies at an altitude of 4,750 feet on the west slope of a low desert range, sometimes known as the Darwin Hills. It is within this range that the mines here described are situated, and the Darwin district, as the term is used in this report, is coextensive with the Darwin Hills. The legally constituted mining district within which it is situated is known as New Coso.

The Darwin Hills trend in a northwesterly direction. They are bordered on the east, south, and west by great gravel washes, but to the north their termination is somewhat indefinite and their identity becomes lost through coalescence with scattered groups of hills. The length of the range is about 6 miles, and the relief is from 500 to 1,000 feet.

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[1] Mineral resources of the Inyo and White mountains, Cal.: U. S. Geol. Survey Bull. 540, pp. 81–120, 1914.

[2] Inyo County: California Min. Bureau Eighth Ann. Rept., pp. 224–226, 1888.

[3] The mineral deposits of eastern California: Am. Geologist, vol. 17, pp. 149–150, 1896.

Physiographically the range has been reduced by long-continued erosion to mature rounded slopes. Rejuvenation has, however, affected the range to some extent within comparatively recent time. This is shown most plainly along the east flank of the southern portion

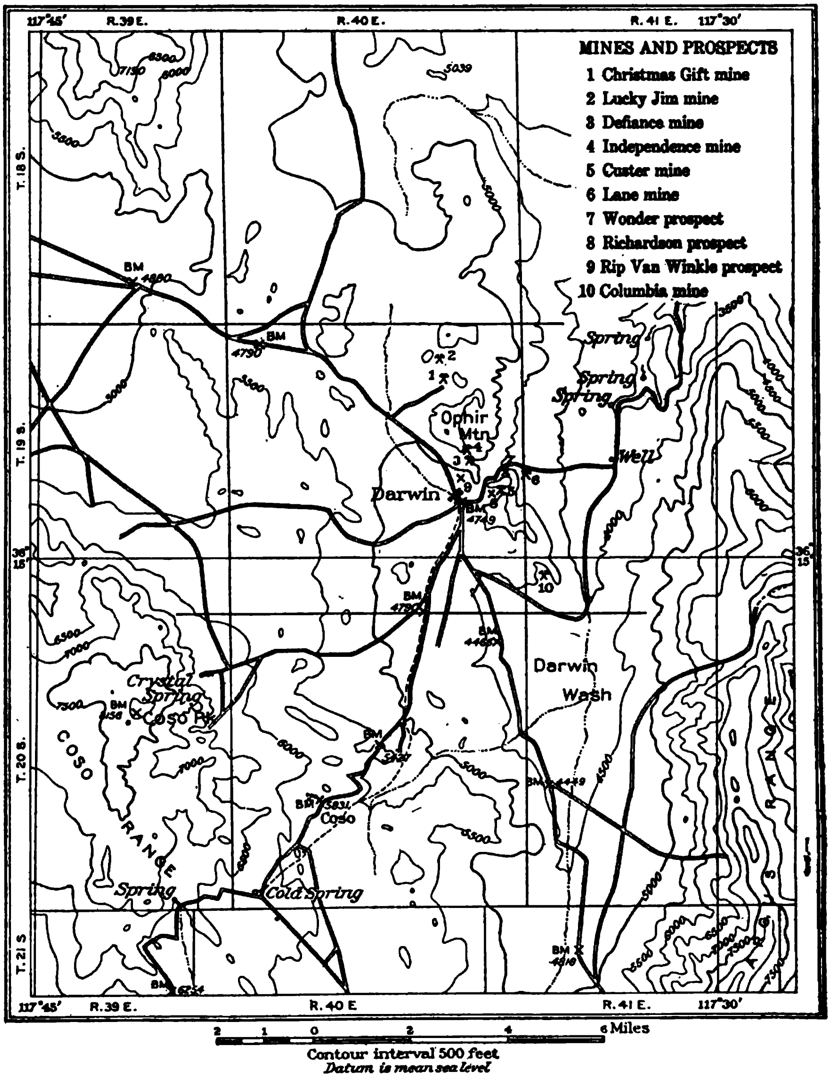

FIGURE 1.—Map of the Darwin district, Cal., and vicinity.

of the range, where recent faulting is strongly indicated. That the east flank of the range is thus determined by a fault scarp is attested by the rugged character of its topography, which contrasts sharply with the smooth rounded slopes on the west side of the range, and this evidence is corroborated by the triangular faceting of the spurs. Toward the north, however, the fault dies out, as is shown by the fact that a series of basalt flows lying across the trace of the fault seems not to have suffered noteworthy displacement. Of interest in this connection is the fault scarp shown by the Argus Range, just east of the Darwin Hills. The face of this range is determined by a series of step faults, exhibited diagrammatically in a displaced series of basalt flows, whose faulted segments form, as it were, the treads of a stairway of four steps ascending from the valley floor to the summit of the range.

MINING CONDITIONS.

The district lies in the desert region of southeastern California and is therefore arid. The average annual rainfall at Keeler, which is the nearest locality for which records are available, is 3.15 inches, and it is unlikely that the precipitation at Darwin exceeds this, although Darwin is 1,100 feet higher than Keeler. Water is piped by gravity from the Coso Mountains, a distance of 8 miles, and was in 1913 sold at half a cent a gallon for mining purposes and 1 cent a gallon for domestic purposes. An ample supply is said to be available at the well at the lower end of the Darwin Wash, but for most of the mines in the district the utilization of this supply would require a lift of 2,000 to 2,500 feet.

Ore is hauled from the mines to the railroad at Keeler at $6 to $8 a ton, either by team or auto truck. Freight brought out to the district costs $1 a ton more. Miners' wages are $3.50 to $4 a day.

HISTORICAL NOTE.

The name Darwin is said to come from Dr. Darwin French, who in May, 1860, led a party of 15 men in search of the Gunsight lode. This lode was a mythical silver deposit believed to have been found by the emigrant party that was lost in Death Valley in 1850.[1] In the early part of the decade between 1870 and 1880 argentiferous lead ores were discovered in the vicinity of Darwin. A town soon sprang up here and is said to have had at one time a population of several thousand inhabitants. The pipe line which brings water from a spring in the Coso Mountains 8 miles distant and which still supplies all water used for mining and domestic purposes in the district was completed in July, 1875.

Between 1875 and 1877 three smelters were built near the town of Darwin. The largest of these, stated to have had a capacity of 100 tons a day, was erected by the New Coso Mining Co., which owned the Christmas Gift and Lucky Jim mines. This smelter commenced operations in 1875, the lead well being started with lead obtained from Cerro Gordo, and a heavy production was maintained during 1876. The Defiance furnace is said to have had a capacity of 60 tons a day and the Cuervo a capacity of 20 tons.

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[1] California Min. Bureau Third Ann. Rept., p. 33, 1883.

These furnaces, after the activities of the first few years, were operated in a desultory way. Expenses were high, because prior to the completion of the railroad to Keeler in 1883, all freight had to be brought across the desert by teams from Los Angeles, a distance of 275 miles. The richer and more easily mined ore bodies were early exhausted, and as the policy of mining in those days did not consider the wisdom of keeping reserves in advance of extraction, the district soon lapsed into stagnation, occasionally interrupted by periods of moderate activity. The smelters have long been dismantled and destroyed, and the ores now produced are shipped to reduction works at Selby or Salt Lake.

In the early part of 1913 there was considerable activity in the district, especially at the Christmas Gift, Lucky Jim, and Custer mines, and it is hoped that the introduction of modern machinery and the inception of systematic exploration work in some of the old properties may result in a permanent revival of the mining industry. A telephone line connecting Darwin with Keeler was completed in May, 1913.

GENERAL GEOLOGY.

SEDIMENTARY ROCKS.

CARBONIFEROUS SYSTEM.

General character.—The Darwin district is prevailingly underlain by a series of stratified lime-silicate rocks including some interbedded limestone. The lime-silicate rocks are generally of light color—white or light greenish—and are fine grained, ranging from microcrystalline to aphanitic. On account of the dense texture, the constituent minerals are not recognizable to the unaided eye, but under the microscope the rocks are found to be composed either of wollastonite, of diopside, of grossularite garnet, or of diverse mixtures of these three minerals. Because the rocks made up of these different lime-silicate minerals can not be distinguished from one another except by microscopic examination, they are as a rule referred to in this report under the general term "lime-silicate rocks."

The strata are considerably folded and somewhat faulted, and because of this structural complexity no attempt was made to estimate their thickness.

The limestone beds interstratified with the lime-silicate rocks, although not numerous, generally carry fossils which serve to determine the age of the formation. Such fossiliferous strata were found at a number of widely separated localities and show that the sedimentary rocks throughout the district are all of essentially the same age—late Carboniferous (Pennsylvanian). Some fossils found near the Columbia mine were submitted to George H. Girty, who has identified the following forms: *Girtyina ventricosa?*, Lophophyllum ? sp., Fistulipora sp.

Metamorphism.—The widespread and thorough metamorphism of the Carboniferous rocks is the salient feature of the geology of the Darwin district. By this process many square miles of calcareous and magnesian strata have been converted to wollastonite, diopside, and garnet rocks. Despite this complete metamorphism they retain their sedimentary appearance; in fact Goodyear, and also Fairbanks, following him, termed them "calciferous quartzites." The rocks preserve their banding and stratification, and careful search failed to reveal anywhere any trace of slumpage or collapse of the beds as a result of the metamorphism they have undergone. The conversion of the carbonates of the original rocks into silicates was attended by the expulsion of large amounts of carbon dioxide, and the preservation of the bedded structure therefore seems to indicate that an enormous quantity of material, principally silica, has been added during metamorphism.

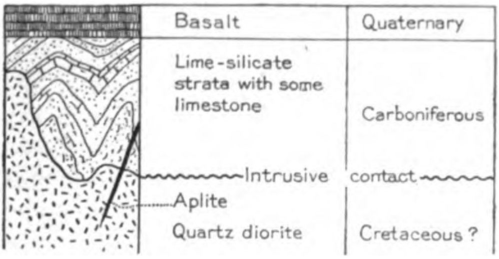

FIGURE 2.—Generalized columnar section for the Darwin district, Cal.

The intensity of these processes is doubtless due to the facts that the Darwin district lies on the margin of the great granite mass that makes up the larger part of the Coso Mountains and that it is underlain at slight depths by granitic rocks, as shown by the multiplicity of dikes and small bosses of quartz diorite and allied plutonic rocks.

Persistent dikes of aplite—pure quartz and feldspar rocks—in places cut the lime-silicate rocks. Some of these dikes, although but a few inches in thickness, show no evidence of chilling of their margins, except where minute apophyses a fraction of an inch thick penetrate the adjacent wall rock. From these facts it may be confidently inferred that the dikes of aplite were injected after the lime-silicate rocks had been formed and before they had greatly cooled.

IGNEOUS ROCKS.

QUARTZ DIORITE.

Granular igneous rocks, as already mentioned, are of common occurrence in this district. The largest mass forms a relatively narrow belt extending for many thousand feet parallel to the general strike of the strata. It lies near the middle of the range and is well exposed near the Defiance mine.

These rocks are generally of medium or fine texture, and owing to the inconspicuousness of the quartz they contain, they are of dioritic appearance. Microscopic study proves that they are of somewhat greater mineralogic diversity than would be suspected from examination by the unaided eye and shows that they range from quartz monzonites carrying hornblende and biotite to quartz-augite diorites. Some, in fact, as those near the Christmas Gift mine, should be termed augite diorite porphyry. The generalized term quartz diorite employed in figure 2 is meant to include all these different rocks.

In places the quartz diorite carries numerous irregularly shaped nodules composed largely of tourmaline, which undoubtedly represent segregations formed during the crystallization of the magma.

The age of these intrusions is post-Pennsylvanian, and from analogy to the occurrences near by in the Inyo Mountains they may be regarded as probably Cretaceous.

GRANITE PORPHYRY.

A mass of granite porphyry about 200 feet in diameter is intrusive into the lime-silicate rocks a mile south of the Christmas Gift mine, on the trail between that mine and Darwin. A dike of the same kind cuts the quartz diorite and shows chilled edges. The granite porphyry is characterized by prominent phenocrysts of orthoclase, plagioclase, and corroded quartz embedded in a light-pinkish groundmass of aphanitic texture. From its general character the granite porphyry is probably to be regarded as one of the latest manifestations of the epoch of quartz diorite intrusions.

BASALT.

Sheets of basalt cap some sloping mesas in the northeastern part of the district. They have neither direct nor indirect relations to the ore deposits and are therefore of no economic concern. The basalt is a fine-grained bluish-gray variety carrying sporadic small particles of olivine. The eruption of these basalt flows is believed to have taken place in early Quaternary time.

ORE DEPOSITS.

GENERAL FEATURES.

The ore deposits are principally bodies of argentiferous lead. They are generally inclosed in lime-silicate rocks, although a few are in limestone and small isolated masses of ore are found in the quartz diorite.

The metalliferous minerals are galena and its oxidation products, cerusite and anglesite; the gangue minerals are calcite and fluorite, both as a rule very coarsely crystalline. Another material common in the gangue, especially in association with the more highly oxidized ores, is an "iron jasper," which is essentially a silica-iron hydrate compound, probably one of the so-called colloid minerals. Pyrite, locally in considerable quantities, and sphalerite to a minor extent occur in the primary ores.

Oxidation has extended irregularly down to the greatest depths attained in the mines—a few hundred feet. No water has yet been encountered.

GENETIC CLASSIFICATION AND CHARACTER.

The preceding paragraphs embrace all the generalizations concerning the ore deposits that can be made in describing them collectively. Nearly all the more important ore deposits have strikingly individual features and must therefore be described individually.

Genetically classified, the ore deposits range from the contact-metamorphic type to fissure fillings of hydrothermal origin at moderate temperatures.

The contact-metamorphic type is represented most clearly by the ore body at the Independence mine. The primary lead ore here consists of galena associated with andradite, and the deposit is situated at the contact of quartz diorite and lime-silicate rocks. Some dark-gray limestone appears a few hundred feet from the deposit, and it is probable that the ore body is a replacement of a limestone bed that escaped alteration to lime-silicate rock. It is noteworthy that the garnet associated with ore deposits is the lime-iron variety andradite, whereas that in the lime-silicate rocks produced by the general metamorphism that affected the district is the lime-aluminum variety grossularite.

The ore body at the Custer mine is probably also of contact-metamorphic origin. The deposit occurs in the broken arch of an anticline, along which the brecciated strata have been recemented by calcite and garnet. The extraordinary coarsely crystalline development of the calcite, cleavage individuals ranging from 12 to 18 inches in diameter being not uncommon, makes this deposit unique in the district. Fluorite is abundantly associated with the galena. Microscopic examination of some veinlets traversing lime-silicate rock, which occurs as an inclusion in the calc-spar on the 300-foot level, shows that they consist of wollastonite, andradite, calcite, and sphalerite.

A transitional type of ore deposit, intermediate between the kind commonly termed contact-metamorphic and fissure veins, is represented at the Defiance mine. The ore occurs as a replacement of a limestone bed underlain by quartz-augite diorite, as illustrated in figure 3 (p. 13). The primary ore as seen in hand specimens consists of galena, pyrite, and sphalerite embedded in a gangue apparently composed wholly of calcite and fluorite. The microscope reveals in addition considerable orthoclase, commonly in euhedral forms. Apatite in characteristic hexagonal cross sections and in stout prisms is inclosed in the feldspar and more rarely in the calcite, where it may even develop in relatively large irregular aggregates. As orthoclase is an uncommon constituent of ores of this kind, its presence was corroborated chemically. Its optical properties show that it is not the adularia variety.

The quartz diorite forming the footwall of the deposit has obviously been pyritized, and examination under the microscope shows further that the augite has been uralitized and the feldspar partly sericitized. It follows, then, that the solutions which brought in the ore minerals caused the formation of orthoclase in the limestone and sericite in the adjacent igneous rock.

Fissure veins constitute the most numerous type of ore deposit in the district. They differ very considerably from those in most lead-producing districts in that the country rock traversed by the fissures is lime-silicate rock. They differ notably, for example, from those of the Cerro Gordo district, near by, where the galena generally occurs as a replacement of a pure calcitic marble. The walls of the fissures are clean-cut, and the filling along barren stretches consists of large masses or breccias of lime-silicate rock. The ore consists of practically solid masses of galena and its oxidation products; the gangue as a rule contains only small quantities of fluorite.

In addition to the various kinds of mineralization described in the foregoing paragraphs, one other was noted, which, although it produced no deposit of commercial importance, is briefly described for the sake of completeness. On the trail half a mile north of the Defiance mine there is a broad zone of fracturing and brecciation in the quartz diorite. Along this zone the quartz diorite has been much tourmalinized, so that the rock is largely replaced by aggregates composed of small radial groups of tourmaline. In places it has also been impregnated with pyrite crystals, now largely converted to limonite.

ORIGIN.

The genetic mode of presentation adopted in the description of the ore deposits has necessarily anticipated in part some of the matter properly belonging to a discussion of their origin.

The mineralogic character of the ore at the Independence mine, as shown by the association of galena with an andradite gangue, is typical of contact-metamorphic origin, and in conformity with current theories it is believed that the deposit was formed from solutions given off by deep-seated magmatic sources. Mineralogically similar deposits are described by Goldschmidt [1] as of common occurrence in the Kristiania region, and he adduces strong evidence that they are of pneumatolytic origin.

The intermediate character of the Defiance ore deposit has already been pointed out. The important diagnostic mineral here appears to be apatite. This mineral, as is recognized by many observers, is not uncommonly developed during contact metamorphism. It occurs, moreover, in tin-bearing veins and is present in gold veins formed at high temperature, both as a constituent of the gangue [2] and as a replacement of the wall rock.[3] It is consequently, when formed as a product of replacement, indicative of origin at high temperature. Its presence in the ore of the Defiance mine as a replacement of limestone, and especially as prisms inclosed in orthoclase replacing limestone, points to the transitional character of the deposit, which therefore forms, according to this interpretation, a link between the contact-metamorphic deposits, as represented by the Independence ore body, and the fissure veins of the district.

The affiliation of the fissure veins with the high-temperature deposits of the district is indicated by the mineralogic gradation that can be shown to exist between them. If this relation, which is so obvious, did not exist, the genetic position of the veins would perforce remain doubtful, as the component minerals are all of the kind termed by Lindgren "persistent" and consequently are of no diagnostic value. The fissure veins, it is apparent from the foregoing statements, are regarded as representing the low-temperature end of a genetically related series of deposits, formed at progressively decreasing temperatures.

The Darwin district is somewhat noteworthy, then, as containing within its small area a complete gradation from contact-metamorphic lead ores to fissure-vein deposits showing the ordinary characteristics of hydrothermal origin. In its genetic features it bears some analogy to the Cœur d'Alene district, where a similar sequence has been traced by Ransome.[4] It differs notably from that district, however, in that at Darwin the end members, presumably formed at cooler temperatures, were deposited in lime-silicate rocks, whereas in the Cœur d'Alene district the principal deposits are inclosed in sericitic quartzites which were not affected by the metamorphic influence of the intrusive monzonite. At Darwin the fissure veins were deposited as near their magmatic source as were the contact-metamorphic deposits, at least in so far as present surface exposures of igneous rocks throw light on this problem; at Cœur d'Alene the character of the mineralization changed progressively with increasing distance from the intrusive monzonite. The most probable interpretation to be placed upon this difference is that whereas the genetic sequence in the Cœur d'Alene district represents a sequence in space, the genetic sequence in the Darwin district represents a sequence in time.

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[1] Goldschmidt, V. M., Die Kontaktmetamorphose im Kristianiagebiet, p. 218, 1911.

[2] Beck, Richard, Die Lehre von den Erzlagerstätten, 3d ed., vol. 1, p. 433, 1909. Lindgren, Waldemar, Mineral deposits, p. 639, 1913.

[3] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 37, 39, 1912. Von Groddeck, A., Neues Jahrb., Beil. Band 2, pp. 87, 102, 1883.

[4] Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Cœur d'Alene district, Idaho: U. S. Geol. Survey Prof. Paper 62, pp. 135–139, 1908.

SUMMARY.

The ore bodies, ranging from contact-metamorphic deposits to fissure veins, are inclosed in lime-silicate strata of late Carboniferous age. The metamorphism of originally calcareous and magnesian beds to wollastonite, diopside, and grossularite rocks is a result of the invasion of the region by quartz diorite, probably in Cretaceous time. Somewhat later than this general metamorphism came the introduction of the ore, and the evidence seems strong that the metallic constituents were given off from deep-seated portions of the same magma from which the quartz diorite now seen at the surface crystallized. The inclosure of the ore bodies in lime-silicate strata is the distinguishing feature of the Darwin district.

The ores consist of argentiferous galena, with minor pyrite and sphalerite, and are associated in most of the deposits with a gangue of calcite and fluorite. As a rule the galena is largely oxidized to lead carbonate and sulphate. There is, however, no evidence of important migration and secondary concentration of silver, lead, or zinc through the action of oxidizing solutions; indeed, such concentration appears unlikely, from the prevalence of calcite in the deposits.

MINES AND PROSPECTS.

CHRISTMAS GIFT MINE.

The Christmas Gift, situated 2 miles north of Darwin, is one of the oldest mines of the district and has been one of its largest producers. According to Mr. L. D. Skinner, one of the present operators, the total production is estimated to be $550,000; this amount was taken from the surface down to a depth not exceeding 230 feet and from a length of 300 feet along the vein. The mine, originally owned by the New Coso Mining Co., was energetically exploited in early days but soon fell into decline and has since been worked in only a small way by occasional lessees. In 1912, however, the property was taken over under a lease and bond, 10 per cent royalty on the ore taken out to apply on the purchase price, and a systematic development of the mine was undertaken in order to determine its possibilities.

The equipment includes a 15-horsepower distillate-engine hoist (sufficient to sink to a depth of 500 feet) and a 40-horsepower distillate engine operating a compressor. The mine is opened by an inclined shaft on the vein, 230 feet long, and by several hundred feet of drifts extending in both directions from the shaft. Exploration from both ends of the lowermost drift was in active progress at the time of visit.

The country rock in the vicinity of the Christmas Gift consists of white lime-silicate rocks pierced by small intrusions of augite diorite porphyry. The lime-silicate rocks are distinctly stratified and, as measured west of the mine, strike N. 30° W. and dip 25° W. Eastward from the mine the rocks are progressively less metamorphic, and a considerable number of beds of Fusulina-bearing limestone, weathering dark blue, are interbedded with the lime-silicate strata. Dikes and small masses of porphyry penetrate the lime-silicate strata in the surrounding area, especially west and southwest of the mine. An intrusion, whose outcrop is 100 feet in diameter, appears one-fourth mile south of the mine. It is a rather dark gray rock displaying a somewhat porphyritic structure on weathered surfaces. Under the microscope this rock, which is ideally fresh, is seen to be composed dominantly of plagioclase and augite. Biotite is a rare constituent. The plagioclase occurs in two generations; orthoclase is present interstitially and incloses the plagioclase of the second generation. Quartz is rare, and apatite and magnetite occur as accessory minerals. The rock may accordingly be designated a diorite porphyry, although closely approaching a diorite in character. Some of the open cuts on the southwest extension of the vein show diorite porphyry which has obviously been altered by garnetization. This is confirmed by microscopic examination, which shows the augite and plagioclase of the igneous rock invaded by a new growth of andradite, epidote, calcite, and titanite.

The vein strikes approximately N. 40° E. and dips 75° SE.; it therefore cuts across the stratification of the inclosing rocks at an angle of 70°. In width it ranges from 2 to 8 feet, averaging 4 feet. The walls are exceedingly well defined and, as seen on the 150-foot and 230-foot levels, show horizontal corrugations. In open cuts northeast of the shaft a dike about 3 feet thick cuts across the vein. The dike is considerably pyritized, indicating that it had been injected prior to the period of deposition of ore in the vein, and although the walls of the vein show strong horizontal scorings, the dike nevertheless is not displaced. This may indicate either that the dike was injected during the interval between the act of fissuring and the period of mineralization, or that the fissuring was produced by oscillatory movement along the fracture zone without essential resultant displacement. Some fissures trending obliquely to the vein exhibit strong vertical corrugations, but no ore has been found in these fissures; the significance of this is not wholly clear.

The lime-silicate rocks of the inclosing strata are generally of microcrystalline texture, but aphanitic varieties occur. The filling of the vein along barren stretches consists of a breccia of lime-silicate rock. Some of this material taken within the vein on the 300-foot level, 100 feet west of the shaft, proved under the microscope to be practically solid wollastonite rock. A specimen from the footwall on the 200-foot level was found to be composed entirely of closely packed grains of diopside. These diverse rocks are indistinguishable to the eye, and similar variation is likely to occur from place to place along the vein, on account of the fact that it crosscuts the stratification of the lime-silicate rocks.

The ore forms irregular masses in the vein. Lead carbonate and sulphate associated with "iron jasper" form a common vein-filling material. The unoxidized ore consists of galena, massive as a rule and containing less than 1 per cent of pyrite. No sphalerite was noted to occur with the sulphides, but the zinc silicate calamine, crystallized in radial groups, was found in the oxidized ore in small quantities; presumably, therefore, zinc blende is a minor constituent of the primary ore. Fluorite, abundant elsewhere in the district, is exceedingly rare as a gangue mineral. The extent to which the ore is oxidized is not closely dependent on depth but was probably determined by the perviousness of individual ore masses. Heavy galena ore appears at a depth of 50 feet west of the shaft, but in other places oxidized ore occurs down to the lowest level.

The production at the time of visit was at the rate of 100 tons a month. The shipments during May averaged 60 ounces to the ton in silver, 45 per cent of lead, and $2 to the ton in gold.

LUCKY JIM MINE.

The Lucky Jim mine, situated a short distance north of the Christmas Gift, was located December 12, 1874. Goodyear[1] wrote in 1888 concerning the Lucky Jim that "Mr. J. A. McKenzie [the owner] thinks [that] this mine has turned out an aggregate of between $1,250,000 and $1,500,000, but that on the whole more money was expended here than was ever taken out, which seems not improbable."

The equipment consists of a gasoline hoist and compressor, and the mine is opened by a vertical shaft 300 feet deep and by an incline extending 180 feet below the bottom level. These figures coincide with those given by Goodyear, so it is evident that no exploration in depth has been attempted since 1888. The mine was operated during the early part of 1913 but was closed in May.

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[1] California Min. Bureau Eighth Ann. Rept., p. 225, 1888.

The geologic features are similar to those at the Christmas Gift mine. The country rock consists of lime-silicate strata cut by a few small bodies of diorite or diorite porphyry, the largest of which in the vicinity of the mine is that near the boarding house. The mineralization also appears to be essentially similar to that at the Christmas Gift, although some barytic ore was noted on the east end of the vein.

DEFIANCE MINE.

The Defiance group consists of four patented and three unpatented claims, situated a mile north of Darwin. The most work has been done on the Defiance mine, and this part of the property has been the largest producer. The last work was done in 1900.

The equipment consists of a steam hoist, the water for which must be pumped from Darwin, overcoming a lift of approximately 400 feet. At the place of maximum mineralization an incline averaging 35° was sunk on the deposit for a distance of 380 feet. From the level at the bottom of this incline, which is known as the fifth, a winze has been sunk to an additional depth of about 100 feet, and some drifting and stoping have also been done here.

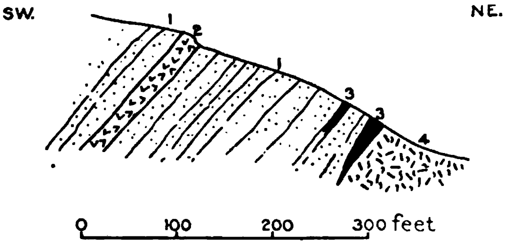

FIGURE 3.—Diagrammatic section across the Defiance ore bodies, Darwin, Cal. 1, Lime-silicate strata; 2, aplitic granite; 3, ore bodies; 4, quartz diorite.

The main ore body lies at the contact of diorite and lime-silicate rocks, as is shown in figure 3. The diorite is a medium or fine grained gray granitoid rock, which, as shown in numerous sections under the microscope, ranges from quartz diorite to quartz monzonite. The quartz is present in moderate quantity, and this fact, together with its interstitial distribution, accounts for its inconspicuousness to the unaided eye. The country rock above the hanging wall of the ore body consists predominantly of brilliant white-weathering lime-silicate strata, striking N. 45° W. and dipping 45° SW. These strata are generally of dense texture, but some beds show small macroscopic garnets, probably grossularite. One of the close-grained varieties examined microscopically consisted of wollastonite with subordinate diopside.

The dike—or perhaps more properly sill, as it lies parallel to the stratification—which is situated some 200 feet stratigraphically above the ore body, is of granitic or aplitic character. It consists dominantly of orthoclase, with quartz and plagioclase, and has been subjected to pyritization, accompanied by the formation of sericite and calcite.

The ore body, which rests on the diorite as a footwall, is from 200 to 300 feet long. At the mouth of the main incline it is 40 feet or more thick and consists of highly oxidized siliceous, gossany fluoritic material, although in this thickness of 40 feet there are included large masses of pure limestone. Evidently the bulk of the oxidized material did not constitute ore, for only a small fraction of it was removed. In places some heavy lead carbonate ore mixed with fluorite, chrysocolla, and other minerals can still be found. A small quantity of galena embedded in fluorite occurs in the outcrop; pyrite is represented by casts and by limonite pseudomorphs. Locally the pyrite casts are coated with minute green crystals of sulphur, as is easily verified by their ready combustibility.

Primary ore seen on the dump (probably in the main low-grade "reject") consists of abundant euhedral pyrite, with galena and resinous sphalerite, in a gangue of fluorite and coarse calcite. The fluorite is white, purple, or green. Chalcopyrite, which is the probable source of the copper in the chrysocolla, is of rare occurrence. Similar material found in place in a drift below the fifth level shows abundant pyrite in well-formed pyritohedral and cubical crystals averaging a quarter of an inch in diameter, together with minor galena and sphalerite, inclosed in calcite and purple fluorite. Under the microscope this material showed in addition considerable orthoclase and some apatite.

The ore of the Defiance mine is reported to have had a value, as sorted and shipped, of $100 a ton in lead, silver, and gold, the gold being present, however, to the extent of $4 a ton.

Above the main ore body of the mine is a short, narrow tabular mass of ore that lies parallel to the strike of the inclosing rock and has been exploited by open cuts.

INDEPENDENCE MINE.

The Independence mine, which is part of the Defiance group, lies north of the Defiance mine at an elevation of 850 feet above Darwin. It is opened by an adit and a network of drifts.

The ore body is situated at the contact of lime-silicate rocks with diorite, which is the northward extension of the belt forming the footwall of the Defiance ore deposit. The showing on the surface is surprisingly small in view of the large amount of mineralized rock revealed in the drifts. Much of this, however, is iron oxide material with some gypsum and sulphur, but one drift shows a good body of lead carbonate ore, though this is said to be low in silver.

Geologically, the most interesting feature of the Independence ore body is the fact that the galena and its alteration products are inclosed in a gangue of garnet of the variety andradite. This gangue is, in general, not easily distinguishable from the lead carbonate, but in places it is well crystallized in green dodecahedrons.

CUSTER MINE.

The Custer mine, which is a short distance east of Darwin, was being worked by a small crew of men during 1913. It is equipped with a 10-horsepower gasoline hoist and is opened by an incline to a vertical depth of 240 feet. Below the lowest level, called the 300, a winze was being sunk at the time of visit.

The property has recently changed hands. The production under the former owners is said to have been $200,000, and under the new management $30,000 was taken out.

The country rock in the vicinity of the mine consists of highly garnetized sedimentary beds, which still preserve their sedimentary banding and stratification. A specimen taken from near the outcrop of the ore body is a remarkably heavy and dense rock of almost chertlike texture; rarely it shows short, narrow calcitic laminæ inclosing small well-crystallized garnets. Such rock proves under the microscope to consist essentially of a dense aggregate of garnet, which has been determined to be the iron-bearing variety andradite. A small intrusion of fine-grained quartz monzonite appears in the tunnel.

Behind the engine house the strata strike N. 25° W. and dip 55° W., but a short distance to the east, near the blacksmith shop, they dip 45° E. The rocks have thus been folded into a sharp anticline, and the arch of this anticline has been broken and the strata brecciated. The breaking of the arch probably took place prior to the garnetization, inasmuch as the breccia is recemented by coarse spar intergrown with garnet.

The ore-bearing zone extends along the broken arch of the anticline. The surface showings give a very inadequate idea of the geologic features of the ore deposit, and especially of the immense spar bodies revealed by the underground exploration. The outcrop appears to represent the apex of a great body of white calc-spar, whose distinguishing characteristic is its extraordinary coarsely crystalline development. Cleavage masses of calcite 6 inches in diameter are abundant, and individuals ranging from 12 to 18 inches are not uncommon. The white spar is more or less studded with crystals of pyrite; on oxidation these cause a darkening of their inclosing matrix. Blocks of lime-silicate rock are present as sporadic inclusions. The shape of the spar mass has been imperfectly determined by mining operations, but locally, as below the 300-foot level, an unbroken stratum of the garnet rock on the west flank of the anticline forms a hanging wall, dipping 60° W.

The ore is found in bunches or pockets distributed irregularly through this great body of spar. Although occurring thus erratically the different pockets are said to be connected as a rule by indications of ore sufficient to serve as guides in the search for undiscovered bodies. The metalliferous minerals are principally lead carbonate and galena. Fluorite occurs invariably in association with the lead ore or in the vicinity of the ore pockets; its presence may therefore be useful as an indication in the exploration for ore. Several hundred tons of coarsely crystalline purple and rose-colored fluorite have accumulated on the dumps.

The ore recently shipped averages 130 ounces to the ton in silver, 10 per cent of lead, and $4 to the ton in gold; it is therefore much more highly argentiferous than the average ore of the Darwin district.

LANE MINE.

The Lane mine is situated a few miles northeast of Darwin, on the east flank of the Darwin Hills. A single-stack water-jacketed blast furnace was built here, but its operations are said to have been unprofitable. Water for the operation of this plant was pumped from wells in the Darwin Wash. The mine is opened by two shafts, one equipped with a steam hoist and the other with a gasoline hoist.

The vein, striking N. 65° E., cuts across the strike of the strata at a considerable angle. The country rock consists of lime-silicate strata interbedded with dark-blue crinoidal and Fusulina-bearing limestones. The primary ore, in part at least, was galena embedded in fluorite, though the principal ore mined was doubtless lead carbonate. On the dumps there is considerable iron-bearing jasper commonly netted with veinlets of chrysocolla.

The depth attained is reported to have been 640 feet, and at that depth the ore is said to have been faulted off. The last shipment of ore, consisting of 42 sacks, was made in 1909 and is stated to have carried 75 ounces in silver to the ton and 48.6 per cent of lead. The total production of the mine is estimated as between $400,000 and $500,000.

WONDER PROSPECT.

On the trail west of the Lane mine is a prospect which shows in exaggerated form the distinguishing features of many of the ore deposits of the Darwin district. The prospect is opened by a short tunnel, and the walls and in places the roof of this tunnel are lined with extremely coarse calcite, cleavage individuals 6 inches and even a foot across being common. Mingled sporadically with this calcite is some coarsely crystalline fluorite. Some lumps of heavy galena ore with fluorite gangue have been piled on the dump. Associated secondary minerals are lead carbonate, linarite, caledonite, and iron-bearing jasper. A small amount of chalcopyrite was noted and is probably the source of the copper in the linarite and caledonite.

RICHARDSON PROSPECT.

At the Richardson prospect, just east of Darwin, a copper-bearing vein has been opened by an inclined shaft about 40 feet deep. The ore is highly oxidized, consisting of chrysocolla, malachite, and a dark-red iron-copper oxide. Chalcopyrite appears to have been the primary sulphide. Fluorite, commonly purplish, and calcite constitute the main minerals of the gangue.

RIP VAN WINKLE PROSPECT.

The Rip Van Winkle prospect is situtated on the west slope of the Darwin Hills a short distance north of town. A shaft 8 feet deep had been sunk on the ledge, but by whom and when had long been forgotten, and the ledge was rediscovered near the close of 1912. Sinking was in progress at two points on the ledge at the time of visit. The ledge is from 4 to 6 feet wide; the outcrop is of a sparry character but of rather inconspicuous appearance, even where it is free from surface débris. The strike of the ledge is N. 60° E. and the dip ranges from 70° SE. to vertical. The inclosing country rock consists of lime-silicate strata. A microscopic examination of a specimen from a horse in the ledge shows that it is essentially a garnet rock; the garnet is colorless, and its refractive index is 1.75, indicating that it is a grossularite.

The ore makes in bunches in the ledge, and this is perhaps the reason why the original locators abandoned the prospect, as the test pit was sunk at a barren point. A coarse calc-spar accompanies the ore, and fluorite occurs in minor amounts. The ore is mainly galena and lead carbonate carrying a subordinate quantity of pyrite. It carries approximately 1 ounce of silver to the ton for each per cent of lead.

COLUMBIA MINE.

The Columbia mine, near the south end of the Darwin Hills, is said to have been located as the Dargon in 1872 but was soon afterward abandoned and lay idle for many years until it was relocated as the Columbia. The total production is estimated to be $75,000. The country rock in the vicinity of the mine is limestone and in general is much less highly metamorphic than in other parts of the district. Crinoidal limestones carrying Fusulina and Bryozoa occur just north of the mine. The ore body consists of a vertical vein ranging on an average from 4 to 6 feet in width, though in places expanding to considerably greater thicknesses. Most of the ore so far extracted has been taken out from a length of about 200 feet, and the extreme depth attained is 225 feet. The ore consists largely of iron-bearing jasper carrying in places lead carbonate and galena. A notable constituent of the gangue is a highly glassy calcite forming an abundant incrustation in the ore. Locally the wall rocks have been recrystallized to a coarse spar. By careful sorting and jigging of the fines a product carrying between 40 and 60 per cent of lead and approximately 1½ ounces in silver to the ton for each per cent of lead is obtained.

R. Gibson

~~R A Crawford~~

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
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BULLETIN 580—B

NOTES ON THE

UNAWEEP COPPER DISTRICT, COLORADO

BY

B. S. BUTLER

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NOTES ON THE UNAWEEP COPPER DISTRICT, COLORADO.

By B. S. Butler.

INTRODUCTION.

The following notes are the result of a visit of two days to the Unaweep district, in September, 1913. The time spent was altogether too short for a detailed study of the geology, and owing to the meager development and the fact that most of the properties were idle opportunity for a very satisfactory study of the ore deposits was lacking. The geology, however, is relatively simple, and it is believed that the more important features bearing on the ore deposits are recorded in the following paragraphs. The writer wishes to acknowledge assistance and courtesies from Mr. J. S. Shaw, of Grand Junction, and Mr. F. B. Grant.

The Unaweep district is located in Mesa County, Colo., 12 to 15 miles west of Whitewater, a station on the Montrose branch of the Denver & Rio Grande Railroad. The wagon road to the district has rather heavy grades for the first 8 to 9 miles, beyond which it follows Unaweep Canyon with moderate grade. The heavy grades are due to the fact that the road passes over a spur of the mesa instead of following the Unaweep Canyon, but a road following the grade of the canyon could be constructed. The bottom of Unaweep Canyon in the central portion of the district has an elevation of about 6,250 feet. Most of the prospects are several hundred feet above the bottom of the canyon. A small stream in the canyon furnishes water for irrigating a few ranches devoted mainly to the raising of alfalfa. Several of the prospects have developed sufficient water for uses other than domestic, and the side canyons have small springs that furnish water for a part of the year.

TOPOGRAPHY AND PHYSIOGRAPHY.

Topographically and physiographically the district is typical of the plateau country. Unaweep Canyon is a great cut through the plateau from the canyon of Gunnison River on the east to that of Dolores River on the west. The divide between the two drainage systems in this canyon is exceptionally low. In the vicinity of the mines the lower 300 feet of the canyon is in granite, the walls rising steeply from the flat bottom. Extending back from the upper edge of the granite is a bench varying from less than 100 to 200 or 300 yards in width. The floor of this bench is the surface of the granite from which the overlying sediments have been removed. Immediately back of the granite bench is a short talus slope formed from a soft shale overlying the granite, and above this rises a nearly perpendicular wall of red sandstone. In the vicinity of the mines this sandstone is about 200 feet thick, but is said to attain a thickness of 400 feet at some localities. On the top of the red sandstone is a second bench bounded by cliffs of gray sandstone, which was not examined, but which has a thickness of several hundred feet.

The granite bench renders building of roads to the prospects relatively easy, as most of the prospects have been developed on this bench or but slightly above it, and few of the side canyons have been cut back across the bench to the base of the red sandstone cliff.

GEOLOGY.

IGNEOUS ROCKS.

The district contains both igneous and sedimentary rocks. The basal formation is a granite that includes irregular blocks of mica and hornblende schist. The granite varies considerably in physical and chemical properties. Much of it is rather uniformly medium grained and is composed of feldspar, quartz, muscovite, and biotite, recognizable in the hand specimen. Under the microscope apatite, rutile, zircon, and magnetite are recognized as accessory minerals. The feldspar is mainly microcline but includes a little plagioclase near albite in composition. The muscovite is as a rule considerably more aboundant than the biotite, though there is considerable variation in the mica content and in the relative proportion of the two varieties.

At some places the granite is very much coarser, containing feldspar crystals as much as an inch in greatest dimension. The coarser type appears to be more siliceous, quartz and pink feldspar being more abundant and the amount of mica being correspondingly decreased. In one specimen examined microscopically titanite is rather abundant. Between the finer and coarser type there are apparently all gradations.

The irregular bodies of schist inclosed in the granite are for the most part mica and hornblende schists, but some of them are very siliceous.

The granite and schist are cut by a great number of pegmatite dikes, which range in size from a few inches to several feet. The dike rocks are usually very coarsely crystalline and are composed essentially of quartz, alkali feldspar, and muscovite. In the larger dikes the individual crystals of the minerals may reach several inches in greatest dimension, and lenses of quartz that extend a few feet along the strike and are 6 inches or more in thickness are not uncommon. The granite is also cut by dikes of diabasic rock. The largest of these dikes observed, in Taylor Gulch, is said to have an average thickness of 200 feet or more. The writer did not confirm this measurement, but the dike seems to have fully this thickness at some points. The dike on the Chance and Bell claims is 12 to 14 feet thick, and the one on the McKinley claim is reported to be of the same thickness, and is generally supposed to be the same dike. There are numerous other dikes of various sizes in the district.

The composition of the dikes varies somewhat, but they are all diabase composed essentially of plagioclase, augite, and magnetite. The rocks have been considerably altered, and an accurate determination of the composition of the feldspar is not possible, but it is probably close to andesine. In most of the dikes the augite has been largely serpentinized.

SEDIMENTARY ROCKS.

The sedimentary rocks of the area consist of shales and sandstones. Lying immediately on the granite is 50 to 70 feet of red ferruginous shale which breaks down readily, forming a talus that obscures the immediate contact. In some places there seemed to be a few inches of a rather fine conglomerate immediately above the granite, but at no point observed was the actual contact of granite and sediments well exposed. Overlying the red shale is 200 feet of red sandstone with beds of fine conglomerate. Above the red sandstone are beds of white to gray sandstone, the thickness of which was not estimated.

No fossils were collected in the district, and the formations were not traced into areas where the age of the sediments has been determined. The beds above the pre-Cambrian farther west in Unaweep Canyon are considered by Cross[1] to be equivalent to the Dolores and La Plata formations of the San Juan region, and the rocks in the Unaweep district are probably to be correlated with these formations.

RELATION OF SEDIMENTARY AND IGNEOUS ROCKS.

The sedimentary rocks at all points where they were observed appear to have been deposited on the granite, and as no dikes were found in the sediments all the igneous rocks appear to be older than the sedimentary rocks. The exact age of the crystalline rocks can not be stated, but there is little doubt that they are of pre-Cambrian age and that they had been deeply eroded before they were covered by the sediments.[2]

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[1] Cross, Whitman, Jour. Geology, vol. 15, No. 7, p. 648, 1907

[2] Idem, p. 676.

STRUCTURE.

The structure of the district is relatively simple. When observed locally the sedimentary beds appear essentially horizontal. As one goes up the valley, however, the surface of the granite is seen to rise from the valley bottom to fully 350 feet above the bottom in a distance of about 3 miles. The dip of the strata is therefore considerably greater than the grade of the stream. The granite surface apparently has a dip of 4°–5° NE.

Some fissuring and faulting have occurred in the district. Many of the dikes, both the pegmatites and the basic dikes, strike about N. 70°–80° W. (magnetic) and dip very steeply. These dikes have evidently occupied fissures. There is also a prominent jointing in the granite having the same general direction.

The fissures that have been occupied by the dikes were apparently formed prior to the deposition of the sedimentary rocks, soon after the granite was solidified, but along some of the prominent fissures there has been movement that has faulted the sedimentary rocks. Such faulting was noted near the McKinley mine, and a fault with 60 to 70 feet throw crosses the canyon 1 to 1½ miles east of Grant's ranch. There has been considerable prospecting along this fault. It strikes in the same general direction as the others and is probably an old fissure which has been reopened.

ORE DEPOSITS.

Copper is the main valuable metal in the district, though the ores contain some gold and silver. It is reported that several carloads of copper ore were shipped about 10 years ago. A matte smelter was erected in the district some years ago, and a few tons of ore treated.

The ore deposits occur in fissures that cut both the igneous and sedimentary rocks. Several of the ore fissures are apparently due to later movements along the fissures in which the basic dikes were intruded, and thus there is apparently a close relation between these dikes and the ore deposits, though basic dikes are not associated with all the deposits.

In the ore deposits associated with basic dikes the vein usually lies along one wall of the dike, between the dike and the granite. The other deposits are distinct fissure veins with granite or shale walls, or where faulting has occurred granite may form one wall and shale the other for short distances. Most of the prospecting has been done in the igneous rocks, though on the Nancy claim ore occurs in the shale a short distance above the granite. Alteration of the massive igneous rocks along fissures has usually been slight, but where the fault fissures have cut the sandstones there has been a marked addition of silica, cementing the sandstones into a resistant quartzite for several feet from the fissure, as is well illustrated 1 to 1½ miles east of Grant's ranch.

The prevailing vein minerals are calcite, quartz, and a little fluorite, together with pyrite and chalcopyrite and in some deposits rather abundant hematite.

Oxidation has not been very extensive, as most of the ore contains a rather large percentage of primary sulphide, even in the shallow workings. The oxidation has resulted principally in the formation of limonite and malachite. A little chalcocite was noted, but there has apparently been very little sulphide enrichment. The copper sulphate resulting from the oxidation of chalcopyrite has apparently reacted with the calcite of the gangue to form the relatively stable copper carbonate. There seems no reason for believing that there has been any considerable migration of the copper or that in the district in general richer or larger ore bodies than those near the surface are to be expected at greater depth. It is of course possible that in an individual deposit the outcrop may chance to be a narrow or lean portion of the vein and that it will be found to be larger and richer at greater depth. It should be borne in mind, however, that the reverse is quite as likely to be true.

There has been considerable prospecting in the district, but most of the properties were idle at the time of visit, and it is therefore impossible to give an accurate description of the different prospects. The deepest mine is the McKinley, which has been developed by a shaft said to be about 600 feet deep. It is stated that at a depth of about 150 feet a small body of ore was encountered. The Nancy is developed by two shafts, each reported to be more than 100 feet deep, and by a tunnel about 300 feet long. A shoot of ore was found near the surface and was followed to a depth of more than 50 feet, and the writer was informed by Mr. J. S. Shaw that 21 cars of ore averaging 16 per cent of copper were shipped from this deposit. The ore on the dump contains pyrite and chalcopyrite with abundant hematite.

The Chance claim is developed by a tunnel 700 feet long connecting with a shaft more than 300 feet in depth. The tunnel follows a basic dike and disclosed small bodies of vein minerals between the dike and the granite walls.

The Bell claim is believed to be on the same vein as the Chance and has been developed by a shaft, said to be about 120 feet in depth, which encountered some ore. There are numerous other claims in the district on which some development work has been done and in which some ore has been found.

O

R. Gibson

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SOME CERUSITE DEPOSITS IN CUSTER COUNTY COLORADO

BY

J. FRED. HUNTER

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SOME CERUSITE DEPOSITS IN CUSTER COUNTY, COLORADO.

By J. Fred. Hunter.

INTRODUCTION.

The following notes are based on information gained during a visit of two days in June, 1913, to the zone of cerusite deposits along Oak Creek in the vicinity of Ilse, Custer County, Colo. One day was spent in examining the Terrible mine, the most important development along this zone, and one day in examining prospects and in studying the character of the zone.

These deposits were first described by S. F. Emmons,[1] who visited the area in 1887 and stated that "the only metallic mineral in the deposit was the white carbonate of lead, or cerusite, which occurred lining the cleavage plane or cracks between the lozenge-shaped fragments of country rock and in some cases as seams or veins a fraction of an inch wide running through the mass or following the footwall." He also noted the absence of sulphides, stated the mineral deposition to be "simply the filling of interstitial spaces in a zone of shattered and altered rock, with possibly a certain amount of replacement of the original minerals," and finally suggested "the transposition and concentration of deep-seated deposits of sulphide by carbonated waters, such as are now issuing at the surface in the canyon of Grape Creek 3 or 4 miles to the westward."

A further reference to the deposits was made in 1907 by R. B. Brinsmade,[2] who described the Terrible mine and offered the curious conjecture that the lead had been derived from "beds of limestone or small veins in the schists" presumably rich in galena and had been deposited as cerusite in the cracks of the gneiss by descending waters. In this way he explained the absence of any galena, even on the 250-foot level of the Terrible mine.

GEOGRAPHY.

The cerusite deposits here described extend in a narrow belt for several miles along the east side of Oak Creek, in the northeastern part of Custer County, Colo., about 12 miles northeast of Silver Cliff.

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[1] Emmons, S. F., The mines of Custer County, Colo.: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, pp. 468-469, 1896.

[2] A curious deposit of cerusite in Colorado: Eng. and Min. Jour., vol. 83, pp. 844-845, May 4, 1907.

The best-known and apparently the richest portion of this zone is in the vicinity of the Terrible mine, close to the nearly abandoned town of Ilse (once known as Spaulding). Prospecting has also revealed considerable ore in the vicinity of Lead Hill, about 2½ miles southeast of the Terrible mine, near the head of the east fork of Oak Creek and on the divide between it and Parker Gulch, a tributary of Hardscrabble Creek. For the most part the deposits occur along the foot of the steep western slopes of the Wet Mountains, a granitic ridge over 9,000 feet in elevation, extending north-northwest to the Royal Gorge of Arkansas River and forming in this locality the Front Range of the Rockies. West of the cerusite belt the low shoulders from these mountains slope gradually to Oak Creek, which in few places is over a third of a mile distant. Oak Creek in this vicinity ranges from 8,100 to 8,400 feet in elevation and flows for the most part through an open cultivated valley, west of which the slopes rise gradually to the divide between it and Grape Creek. At Yorkville, about 5 miles north-northwest of Ilse, Oak Creek turns sharply to the northeast and enters a canyon, from which it emerges to empty into Arkansas River a mile above Florence.

The nearest railroad station is Westcliffe, the terminal of a spur which leaves the main line of the Denver & Rio Grande Railroad at Texas Creek. Westcliffe is 16 miles southwest of Ilse and is connected with it by a moderately good road. Probably the best outlet for the area is at Chandler, the terminus of another short spur line of the same railroad, 17 miles north of Ilse over a good wagon road, most of which is down grade. Rockvale is 18 miles and Canon City, on the main line, 22 miles from Ilse. A branch of the Denver & Rio Grande Railroad which ran up Grape Creek was abandoned in 1888. The post office of Ilse was formerly at the Terrible mine, but after the cessation of activities there it was removed to a ranch about half a mile farther up the valley.

The area lies practically in the center of the Canon City quadrangle, the topography of which was surveyed in 1889 and mapped on the scale of 1 : 125,000. Six or seven miles to the southwest is the northeastern boundary of the Silver Cliff and Rosita Hills area,[1] which has been mapped topographically and geologically on the scale of 1 : 20,000.

HISTORY.

The cerusite belt is said to have been discovered about 1879 by a Mr. Rain, who, with his partner, a Mr. Spaulding, located what is now the Terrible mine. During the period from 1884 to 1889 concentrates were shipped by the Omaha & Grant Smelting Co. from this mine to

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[1] Cross, Whitman, Geology of Silver Cliff and the Rosita Hills, Colo.: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, pp. 263–403, 1896.

Blackburne over the now abandoned Grape Creek road. This was the period of greatest activity in the area, and during it considerably over $500,000 worth of lead was extracted. In 1889 activities at the Terrible mine ceased, owing in part at least to the washing out of the railroad, and nothing more was done until 1897.

During the three years subsequent to 1897 S. H. Baker leased the Terrible property and is said to have extracted about 1,000 tons of ore, running about 5 per cent of lead. During a portion of this time the ore was roasted and converted into litharge. In 1903 the mill, shaft house, and adjoining buildings of the Terrible mine were destroyed by fire, and little or no work has been done since, although several unsuccessful attempts have been made to renew operations. In 1907 the present machinery was installed and the water pumped out, but nothing further was done. In the summer of 1913 the water was again pumped out and examinations were made preparatory to a renewal of operations. At the date of writing, however, the mine is still idle.

Several smaller mines along the cerusite zone have shipped a little ore from time to time. Probably the only one of these deserving mention is that on the Wild Girl and High Kicker properties, near Lead Hill, located about 1887 by Alexander Hall and worked periodically by him until 1893. The shipments from this mine are said to aggregate about 80 tons of concentrates.

Estimates of the total production of the belt vary from $500,000 to over $1,000,000 worth of lead. Except for the record of 3,000 tons of lead produced in the year 1883,[1] no authenticated statistics of the annual production are available. R. B. Brinsmade[2] is authority for the statement that the Terrible mine had "produced some 250,000 tons of ore, from which over $500,000 worth of lead concentrates were extracted and shipped." According to S. F. Emmons,[3] the mint reports up to 1895 showed a production for the Terrible mine of $759,717 worth of lead, all of which went to a single smelter.

GEOLOGY.

GENERAL FEATURES.

The country in the vicinity of the cerusite belt is formed chiefly of granite, in the main of a markedly gneissoid character, which has been intruded by dikes and small bodies of syenite, diorite, pyroxenite, and perhaps other types of rocks. In the short time and with the poor base map at the disposal of the writer, only the most general observations could be made. However, Cross[4] has described the adjacent

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[1] U. S. Geol. Survey Mineral Resources for 1885, p. 256, 1886.

[2] Loc. cit.

[3] Op. cit., p. 420.

[4] Cross, Whitman, loc. cit.

Silver Cliff and Rosita Hills area, where a basement of ancient gneisses and granites, cut here and there by dikes and stocks of syenite, diabase, and diorite, is covered in large part by volcanic rocks of massive and fragmental character, chiefly rhyolites, trachytes, dacites, and andesites. Except for alluvium, local and probably recent lake beds, and stratified rhyolitic tuffs of the Silver Cliff Basin, no sedimentary formations were found in that area.

In the portion of Oak Creek valley examined by the writer no sedimentary or volcanic rocks were observed, and an examination of the float and talus on the western flanks of the Wet Mountains adjacent to the cerusite belt, as well as the form of the exposures, indicated that they consist largely of the gneissoid granite.

The age of the gneissoid granite is not definitely known, but the occurrence of somewhat similar granites underlying Ordovician formations and containing numerous large fragments of Algonkian quartzite in the Pikes Peak quadrangle,[1] which lies immediately north of the Canon City quadrangle, makes it probable that they belong to the Algonkian or early Cambrian. The gneisses west of the cerusite belt, which are cut by these granites, may be Archean, although there is no direct evidence on this point. The age of the syenites, diorites, and pyroxenites presently to be described is also indeterminable.

PETROGRAPHIC CHARACTER OF THE ROCKS.

Granite.—The prevalent rock in the vicinity of the cerusite deposits is granite, which locally is much crushed, altered, and iron stained. At a short distance away from the metallized belt, however, the rock is fresh and of pinkish color, with numerous dark spots or streaks. Its texture is slightly porphyritic to equigranular or aplitic and of medium grain. The granites on the west side of the zone appear to be more crushed, more gneissic, and more distinctly banded than those on the east side of it. Pinkish feldspar, translucent quartz, and dark-green biotite are the chief minerals of the granites and can easily be distinguished with the unaided eye. The microscope shows that the constituent minerals of these rocks range from 1 to 5 millimeters in diameter and are allotriomorphic—that is, they are without definite crystal boundaries. Feldspar is slightly more abundant than quartz. Biotite and locally muscovite occur in subordinate amounts. The feldspar consists chiefly of orthoclase, microcline, and microperthite, with a small proportion of soda plagioclase, and is in part altered to sericite. Micropegmatite, apatite, and magnetite or ilmenite occur in meager quantities as accessories.

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[1] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (No. 7), 1894. In this folio the formations now known to be Ordovician were included in the Silurian.

Syenite.—At two places along the belt syenite dikes very closely resembling those in the Silver Cliff district were observed. They are conspicuous even from a distance, owing to the red color of their outcrops. A typical example of such a dike is on a sharp spur three-fourths of a mile southeast of Putnam Bros.' ranch house, only a short distance west of the altered cerusite-bearing zone. This dike is 10 feet wide, runs N. 15° W., and can be traced for several hundred yards. The rock is of brick-red color, of fine grain, and of slightly porphyritic texture, a few scattered platy crystals of red feldspar or long needles of dark-greenish amphibole being noticeably larger than the other constituent minerals. Microscopic examination shows the rock to be of allotriomorphic texture and to consist in large measure of feldspar, chiefly orthoclase with undetermined amounts of soda plagioclase. Both feldspars are equally impregnated by fine particles of hydrous iron, which impart the red color and obliterate certain characteristics that are of diagnostic importance in their study. Biotite, magnetite or ilmenite, apatite, epidote, and amphibole are present in subordinate or accessory amounts.

Diorite.—Here and there along the cerusite belt are small bodies of intrusive diorite, the best examples being found on the west side of the open cut at the Terrible mine and on the west side of the southeast fork of Oak Creek, three-fourths of a mile south of Putnam Bros.' ranch house. These bodies are dikelike in form, but as a rule are poorly exposed. The occurrence at the Terrible mine is typical, although it has suffered considerable weathering and alteration near the surface. It is approximately 25 feet wide and appears to run a little west of north, parallel and contiguous to the cerusite-bearing zone. Much of the rock is highly altered and is greenish gray on fracture surfaces, with yellow and brown stains. Where weathered, as in the open cut of the Terrible mine, it is soft and disintegrates easily into rather coarse granular fragments. A fresh specimen obtained near the bottom of the Terrible shaft is nearly black in color, of moderately fine grain, and of uniform texture, and hornblende and feldspar are easily distinguishable in it. The microscope shows that this rock is made up of rather well formed crystals from 0.5 to more than 1 millimeter in diameter. Plagioclase of the composition of calcic andesine is present in slightly greater abundance than hornblende, and these, with a much smaller amount of augite, are the principal mineral constituents. Magnetite in moderately large grains is a relatively abundant accessory, but apatite and pyrite are to be found only here and there. Small amounts of quartz and orthoclase were observed in one of the specimens of diorite studied. In the process of alteration the feldspars have been partly changed to fine sericitic aggregates, while the hornblendes and augites have been deeply stained with hydrous iron, particularly along the cleavage cracks, and in extreme cases have been rendered opaque. Biotite was seen in one slide and is apparently an alteration product of hornblende.

Pyroxenite.—An interesting rock occurs in a small pluglike mass on the east slope of the southeast fork of Oak Creek about 2 miles southeast of Putnam Bros.' ranch house and a short distance west of the High Kicker claim. The exposure is an odd-looking rounded protuberance about 6 feet in diameter, projecting several feet above the surrounding slope. The rock, which intrudes granite gneiss, shows a rough and pitted surface, mostly stained brown or red by iron. On fresh fractures it is black and coarsely granular with large platy crystals of pyroxene which on very close inspection show a mottled surface sometimes called "luster mottling." Microscopic study of one section of this rock showed its individual minerals to average more than 5 millimeters in diameter, to be of irregular and even ragged outline, and to possess a poikilitic structure, that is, it shows inclusions and intergrowth of small particles of one mineral in the larger crystals. The section examined consists largely of hypersthene, with a smaller amount of hornblende and still less olivine, magnetite, and serpentine. The hypersthene shows numerous inclusions or intergrowths of green hornblende. The serpentine fills small cracks and veinlets through the rock and has resulted in part from an alteration of the olivine.

The unusual rock here described belongs to the pyroxenites and suggests certain hypersthenites from Canada and Montana. It is also similar to a peridotite occurring on the northern bank of Cottonwood Gulch east of Querida, near the Hector and Mountain Boy mines, described by Cross.[1] In that rock, however, the olivine and hornblende predominate over the hypersthene, and biotite and plagioclase are present in small quantities. A further study of thin sections from this mass might well reveal larger proportions of olivine and greater similarity to the peridotite.

STRUCTURE.

The rocks of the portion of the Oak Creek valley adjacent to the cerusite belt are granites and granite gneisses intruded here and there by the rocks just described. Only where the gneissic character has been well developed and a marked banding produced can they be said to possess any structure. Although this character is not everywhere manifest and has not been studied in any detail, the observations so far made point to a possible interesting fault relation. The banding or gneissic structure, noted on the east side of the cerusite-bearing zone, trends in general a little west of north, parallel to the zone, but on the west side the structure shows a tendency to a northeasterly or easterly trend such as exists in the gneisses of the Silver Cliff area. Furthermore, this zone extends in a north-northwest direction through small saddles and over gently sloping shoulders at the foot of the abrupt, scarplike slopes of the Wet Mountains, separating the rugged topography on the east and a somewhat gentler surface on the west and thus suggesting a fault zone. Finally the cerusite belt itself shows a notable amount of crushing, with slickensided surfaces in numerous places, and is characterized by gouge, clay selvage, and alteration. For these reasons it is believed that the cerusite zone corresponds to an ancient fault of no small proportions. Owing to the absence of bedded deposits or other structural features than those noted, no idea can be obtained of the character of this fault, or of the amount of displacement effected by it.

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[1] Cross, Whitman, Geology of Silver Cliff and the Rosita Hills, Colo.: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, p. 283, 1896.

MINERAL ZONES.

The only mineral deposits examined in this hasty reconnaissance were the cerusite bodies on Oak Creek. These deposits, where seen, are chiefly localized along zones of faulting and crushing in the granite and granite gneiss. The most important of these zones is the one along the foot of the steep scarps of the Wet Mountains, extending from the Terrible mine in a south-southeasterly direction for at least 2 miles. Near the head of the southeast fork of Oak Creek, in the vicinity of Lead Hill and extending through the Wild Girl and High Kicker properties, is another cerusite-bearing zone, in similar rocks, which probably runs nearly parallel to the first, but appears to be too far east to be a continuation of it. This zone likewise shows evidence of faulting and crushing. A trip southeastward over Lead Hill into Parker Gulch revealed so much cerusite strewn over the slopes as float that the existence of other bodies and zones of cerusite than the two mentioned seems very probable.

The zone first noted can be traced from the Terrible mine, where it is best exposed and northwest of which it is reported to be lacking, in a S. 20° E. direction along the east side of Oak Creek for nearly 2 miles, to a point where it swings somewhat to the east. At the southernmost locality examined, three-fourths of a mile south of Putnam Bros.' ranch house, it runs in a S. 50° E. direction. This zone, which is believed to be coincident with the fault zone described above, is conspicuous even from a distance by reason of the line of yellow, iron-stained exposures and prospects along it.

In the open cut at the Terrible mine the zone consists of about 75 feet of crushed, altered, and iron-stained granite and granite gneiss carrying cerusite, striking N. 20°–25° W. and dipping about 60° SW. It shows a well-marked slickensided and striated plane on the east or footwall side, beyond which there is little if any cerusite, although alteration and oxidation have been effective for some distance farther. On the west or hanging-wall side the pay zone is bordered by about 15 feet of clay gouge with brecciated fragments of altered granitic material. Beyond and parallel to the gouge there is a dike-like body of diorite at least 25 feet wide, which at the surface appears as a soft crumbling mass of blue to greenish-gray material to which tricks of weathering have added all sorts of yellow and brown tones. Several small lenticular masses of granite that may be either intrusions or inclusions are contained in the diorite, which on the first level of the mine is comparatively fresh and unaltered, as described above. The clay gouge and diorite are totally without minerals of economic importance and constitute what is known locally as the "barren zone" or "the gouge." Figure 4 represents a section across the open cut of the Terrible mine.

For 2 miles south of the Terrible mine the so-called cerusite zone can be followed almost continuously and ranges from a belt 80 feet in maximum width at this mine to a mere band of slightly altered and iron-stained gneiss only a few feet across. In several places prospects reveal a narrow zone of intensely crushed rock consisting chiefly of clay gouge, feldspathic material, calcite, and chloritic micas with limonite and manganese stains. On either side of such a zone, which is rarely over 10 feet wide, the granite gneiss may be considerably altered, although as a rule it is but little crushed and grades into fresher rock. Small amounts of cerusite are said to occur here and there along this portion of the zone, but the writer failed to observe any in the few prospects examined.

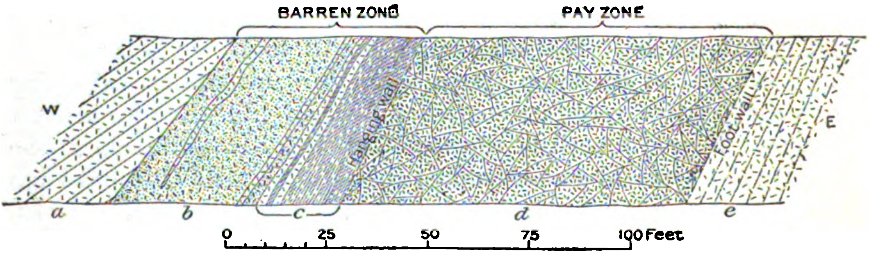

FIGURE 4.—Section across the cerusite belt near Ilse, Custer County, Colo., at the open cut of the Terrible mine. *a*, Gneissoid granite; *b*, disintegrated diorite; *c*, clay gouge with fragments of granite material; *d*, crushed, altered, and iron-stained granite with calcite and pockets of cerusite; *e*, granite.

The other important cerusite-bearing zone visited is that crossing Lead Hill and the High Kicker property. The country rock here is chiefly granite and gneiss, the latter in places being rather micaceous and containing one narrow band of very hornblendic gneiss. The exposures and prospects were not such as to permit conclusive statements, the critical portion of the High Kicker mine not being open for examination at the time of visit. However, several small open cuts above the mine indicate an ore body whose strike probably approximates that of the Terrible zone—N. 15°-25° W.—and which dips westward at a relatively small angle, possibly 30°-45°. In two of the prospects there is a well-marked hanging wall of little altered gneiss whose banded structure is discordant with that of the underlying altered zone. Next below the hanging wall is a seam of gouge 10 to 14 inches thick, under which is crushed and altered gneissoid granite that carries the cerusite. No sharp change of rock or structure indicative of a footwall was found. The cerusite is said to become gradually less abundant eastward from the hanging wall. The width of this ore-bearing zone could not be ascertained, although it does not appear to be comparable to that at the Terrible mine. To the south a line of cerusite float, thought to be a continuation of the High Kicker body, could be followed for at least a quarter of a mile, and to the north of that property there is said to be on the same lead a small working which at one time shipped a small amount of cerusite ore. Although the parts of this zone examined indicate neither the degree of shattering and alteration nor the width that characterizes the Terrible zone, the ore-bearing portion appears to persist for a greater distance along it.

ORE DEPOSITS AND MINERALS.

Although the zones of alteration are extensive, they are cerusite bearing only in certain portions. In the 3 miles or more of the cerusite belt passing through the Terrible mine, the only economically important occurrence of ore so far known is at that mine. Even here the cerusite seems to give out within a short distance toward the south and probably within a somewhat greater distance toward the north, so that the deposit has the character of a shoot, roughly elliptical in plan, plunging to the northwest at an angle of approximately 60°. The shape of the ore body or bodies in the vicinity of Lead Hill can not be known until further development work has been done.

Everywhere throughout the zones of alteration studied the exposures indicate extensive oxidation, the yellow ferrous hydrate with calcite being almost invariably present. The portions of the zones carrying cerusite show extensive crushing, leaching, and infiltration of surface material in the upper weathered parts. A honeycombed structure of limonite and granitic material, together with numerous black manganiferous stains and dendritic wad, such as is typical of the gossan or oxidized portion of veins, is common. Streaks and veinlets of chert and chalcedony occur in small quantities here and there throughout the mineralized portions of the rock. The microscope shows the material of the zone of crushing to be chiefly calcite in very fine grains, a small fraction of a millimeter across, in a fine meshwork of limonite and iron stained material. Small patches of chalcedony together with altered fragments of feldspar, quartz, and mica, all constituents of the original granite, are very abundant. The specimens from the 200-foot level of the Terrible mine show somewhat less calcite and limonite and lack the strongly leached, honeycombed structure of the more superficial parts of the zone. The 250-foot level, the lowest working of the mine, was inaccessible, but the deposits there are said to be similar to those nearer the surface, except that the percentage of lead is somewhat lower.

The ore mined is reported to have averaged from 5 to 8 per cent of lead and was capable of being concentrated to a product running from 60 to 70 per cent of lead. The assays are said to have reported, in addition to lead, a small amount of silver, but no zinc, arsenic, antimony, or sulphur.

Cerusite (the carbonate of lead, $PbCO_3$) is the only valuable mineral of the deposits under discussion which is present in abundance. It occurs as a gray to white heavy massive or granular mineral with numerous good cleavage faces that exhibit adamantine to vitreous luster. It can be distinguished by its high specific gravity and its solubility with effervescence in dilute nitric acid, also by the fact that it yields globules of lead when highly heated. No traces of a remnant of galena could be discovered in the cerusite. It is deposited in the interstices in the zone of shattered and altered rock, where there has been little if any replacement of the original minerals. It occurs in lenses, stringers, threads, and small pockets of diverse shapes along the cracks and jointings of the country rock. Few of these masses are over an inch or two in thickness, although exceptional pockets are 6 or 8 inches across, and even larger masses up to 115 pounds are reported.

One specimen of phosgenite (a chlorocarbonate of lead, $(PbCl)_2CO_3$ or $PbCO_3.PbCl_2$), carrying 81.9 per cent of lead oxide, was obtained. This mineral, which contains nearly as much lead as cerusite, is somewhat rare. As found at the Terrible mine it is dark brown and translucent and has perfect cleavage and adamantine luster. It occurs within a mass of cerusite, and so far as could be determined from one thin section the two minerals appear to have been deposited contemporaneously.

A very little hematite was found on the first level of the Terrible mine, and a few copper stains were observed in the open cut near the hanging wall. A minute particle of sulphide, thought to be chalcopyrite, was found along the zone of alteration on the slope southeast of Putnam Bros.' ranch house, but no other sulphides or sulphates of any kind were observed or are known along this zone, not even, it is said, in the lowest working of the Terrible mine. Indeed, drill holes to greater depths than the Terrible are reported not to have found sulphides.

GENESIS OF THE ORES.

With the growth of knowledge concerning ore deposits, the suggestion offered by Emmons in 1895 that this cerusite has resulted from "the transposition and concentration of deep-seated deposits of sulphides by carbonated waters, such as are now issuing at the surface in the canyon of Grape Creek 3 or 4 miles to the westward," has become less probable. So far as the writer has been able to learn no considerable amount of cerusite is known to have been deposited from springs. Indeed, the lead carbonate is difficultly soluble, as is demonstrated by its occurrence in the soil of Lead Hill.

The mines along the cerusite belt have not been worked to any great depth, so that only the upper portion of the ore deposits known as the oxidized zone has been opened for examination. However, the form and character of the deposits here described indicate that they have originated as veins formed along one or more zones of faulting. The crushed and shattered materials of these zones have afforded effective channels for the circulation of surface waters, so that oxidation has been carried to a somewhat greater depth than in the neighboring lead veins. If this hypothesis is correct, galena, from which the cerusite has very probably been derived, should be expected with increasing depth. The reported occurrences of galena veins on Oak Creek 3 miles above Ilse (at the Francklyn mine), on the west slope of the creek, not far from the Terrible mine, and in the vicinity of Yorkville, together with the occurrence of the meager trace of sulphide (chalcopyrite?) along the belt as described, lends credence to this view. It is of course possible that the galena represented an enrichment of the upper parts of the veins and that oxidation has involved all of this enriched zone, leaving only low-grade sulphides below. The workings accessible at the time of visit threw no light on this question. So far as known there is no other mine in the district which exhibits as deep oxidation as the Terrible.

MINES OF THE CERUSITE BELT.

TERRIBLE MINE.

The only important mine of the district is the Terrible, on the east side of Oak Creek at the former town of Ilse, less than half a mile north of the present Ilse post office. The property consists of a group of patented claims with mill sites aggregating 45 acres lying in secs. 17, 18, 19, and 20, T. 21 S., R. 70 W., and is owned by the Oak Creek Mining & Reduction Co. of New York. The workings consist of a large open cut or quarry, together with underground crosscuts, drifts, and stopes. (See fig. 5.) The quarry is about 50 feet deep, more than 300 feet long, and 115 feet across at its widest part, but narrows at either end and toward the bottom, where it is 75 feet wide. An incline from the west, about 100 feet long, formerly served as a haulway from the bottom of the open cut. West of the quarry, on the hanging-wall side, a shaft, which was aimed to cut the ore body at a depth of about 550 feet, has been sunk 250 feet. From this shaft crosscuts have been driven in a northeasterly direction to the ore body at the 200 and 250 foot levels. Drifts have been cut from these levels, chiefly to the north, and considerable stoping has been done, the first level having been stoped out within 15 feet of the bottom of the quarry. The Terrible mine is reported to take in an average of 280 to 300 gallons of water a minute, which, when not pumped out, will fill it within 50 feet of the surface.

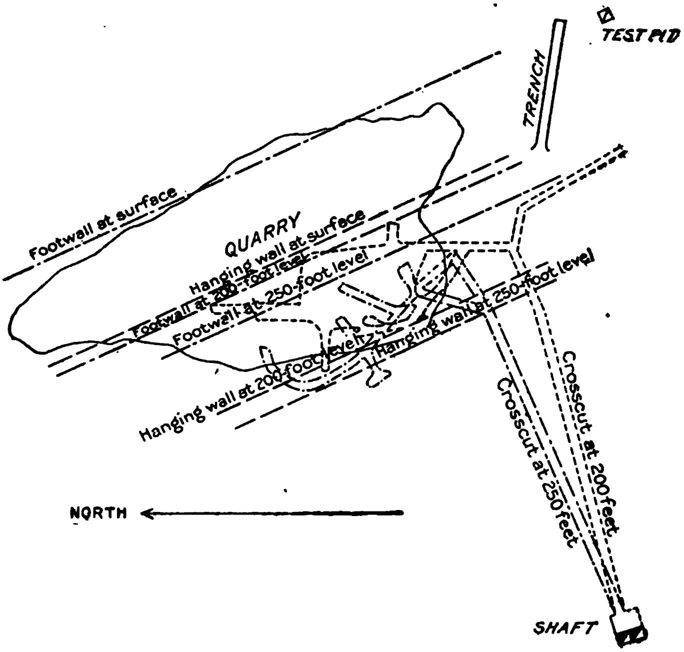
TEST PIT
TRENCH
Footwall at surface
QUARRY
Hanging wall at surface
Footwall at 200-foot level
Footwall at 250-foot level
Hanging wall at 250-foot level
Hanging wall at 200-foot level
Crosscut at 200 feet
Crosscut at 250 feet
NORTH
SHAFT

FIGURE 5.—Plan of the Terrible mine, near Ilse, Custer County, Colo.

The mill, shaft house, and adjoining buildings were destroyed by fire in 1903, and the present surface equipment consists of hardly more than temporary machinery for pumping. The ore was formerly concentrated by the use of the ordinary crushers, sizers, jigs, and tables, and during the last days of activity the concentrates were converted into litharge by means of a small brick reverberatory furnace and a pebble grinder. Though containing more or less impurity, the litharge produced in this way by one heat is said to have been of superior quality, particularly for use in vulcanizing rubber and as a chemical reagent, owing to its freedom from shots of metallic lead.

WILD GIRL AND HIGH KICKER CLAIMS.

The development of second importance along the cerusite belt is that near Lead Hill, on the claims known as the Wild Girl and High Kicker, lying in the N. ½ sec. 33, T. ~~3~~21 S., R. ~~2~~70 W., of the sixth principal meridian. These two claims were located by Alexander Hall about 1887. From that time until 1893 he mined cerusite periodically, chiefly by drifting, concentrating his ore by use of a hand jig and shipping in all about 80 tons of concentrates. The ore-bearing portions of the mine were for the most part fallen in at the time of the writer's visit. A number of prospects, pits, drifts, and tunnels had been driven in the vicinity in an effort to locate the ore body. The property is said to have been patented about 1898 and is now in the possession of Sylvester G. Williams, of Denver, who has recently done some work preparatory to further exploration and development.

OTHER CLAIMS.

Numerous prospect shafts, drifts, and tunnels have been driven at different places along the cerusite belt in search of ore. Several of these prospects visited by the writer showed little or no indication of the presence of ore. A very large portion of the zone of alteration is superficially, at least, barren of valuable deposits.

Two claims known as Moore's property, north of the High Kicker lead and thought to be on it, are said to have shipped in 1908 a small quantity of ore which had been concentrated by hand jigging to material containing 63 per cent of lead. The development on these claims, which were located some 20 years ago and are now held by A. D. McKenzie, of Greenwood, Colo., is reported to consist of a 40-foot shaft and a 50-foot tunnel.

R. Gibson
~~R D Crawford~~

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 580—D

THE
GRAND GULCH MINING REGION
MOHAVE COUNTY, ARIZONA

BY
JAMES M. HILL

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UNITED STATES GEOLOGICAL SURVEY

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THE GRAND GULCH MINING REGION, MOHAVE COUNTY, ARIZONA.

By James M. Hill.

INTRODUCTION.

Early in November, 1913, a few days were taken from a reconnaissance of some mining camps in eastern Nevada for a hasty trip to the Grand Gulch and Bronze L mines in northwestern Arizona. Mr. S. R. Callaway, superintendent of the Grand Gulch mine, supplied many details that have been incorporated in this report. To Mr. Whitehead, of Overton, and Messrs. Genty and Syphus, of St. Thomas, the writer is also indebted for courtesy in supplying information and for samples of ore.

GEOGRAPHY.

The Bently mining district is in that part of Mohave County, Ariz., which lies north of Colorado River and embraces the extreme western part of the Colorado Plateau. It forms a part of the region sometimes colloquially called the "Arizona Strip." So far as could be learned the boundaries of the district are indefinite. In the examination on which this paper is based only the Grand Gulch mine and the Bronze L mine, on the terrace above and immediately east of the Grand Wash, were visited. These mines are 8 miles west of Pigeon Spring, which, according to the edition of the General Land Office map of Arizona for 1912, lies near longitude 113° 45′ W. and latitude 36° 15′ N. The region is also represented on the Mount Trumbull topographic sheet of the United States Geological Survey. (See fig. 6.)

ECONOMIC CONDITIONS.

TRANSPORTATION.

The district is most easily reached from Moapa, Nev., on the main line of the San Pedro, Los Angeles & Salt Lake Railroad, 28 miles northwest of St. Thomas, Nev., the shipping and supply point for part of southeastern Nevada and northern Arizona. A branch railroad runs from Moapa to St. Thomas, but except in the summer during the cantaloupe season no regular service is maintained over this branch.

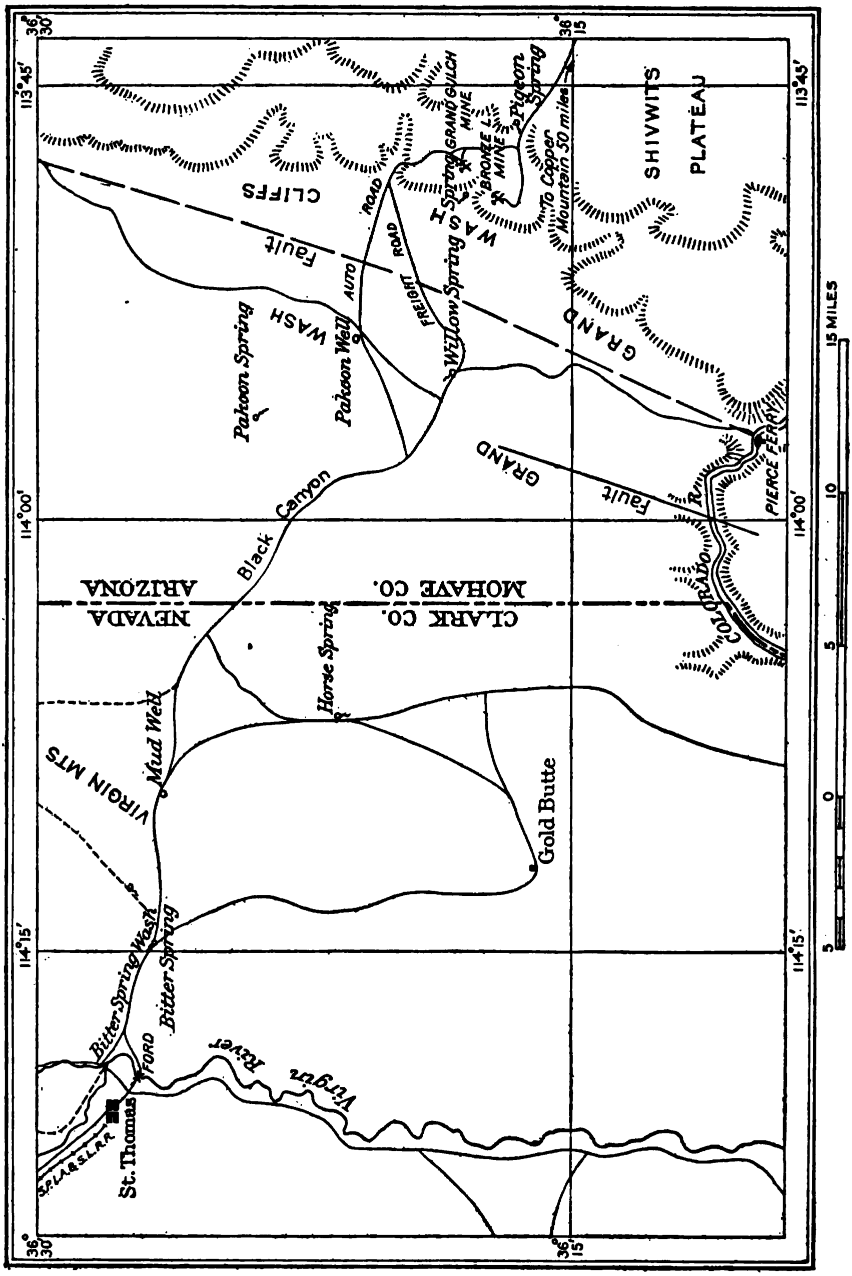

FIGURE 6.—Sketch map showing location of the Grand Gulch and Bronze L mines and the roads and watering places between St. Thomas, Nev., and Grand Gulch, Ariz. Adapted from St. Thomas and Mount Trumbull topographic sheets, United States Geological Survey.

The Grand Gulch mine is 54 miles by road east of St. Thomas. The road crosses Virgin River by a ford 2 miles east of St. Thomas, beyond which an ascent of 1,300 feet in 16 miles along the bottom of a narrow canyon carries it to the summit of Bitter Springs Pass over the Virgin Mountains. The road continues on the south bench of Black Canyon to a point about 2 miles from Grand Wash, which is crossed at either the Willow Spring or the Pakoon Well crossing. For about 6 miles east of the crossing the road passes over the low bench of Grand Wash to the base of the Grand Wash Cliffs, 1,250 feet high, which are ascended by a tortuous but well-constructed grade, up a narrow canyon that opens to the north. The mine is about 2½ miles south of the place where the road reaches the top of the first line of cliffs, but to avoid a deep canyon a detour of 4 miles is made to reach the camp.

The Bronze L mine is about 3 miles a little west of south of the Grand Gulch mine. To reach it the road goes about half way to Pigeon Spring around the narrow gorge known as Pigeon Spring Canyon.

For the most part these roads are rather sandy, and at the time of visit they were excessively dusty and cut by deep ruts and "chuck holes," owing to the lack of rain for many months. Freight teams take a week to make the round trip between the Grand Gulch mine and St. Thomas, hauling from 8 to 12 tons, at the rate of $10 a ton. From 6 to 10 horses are used, and usually the freighters travel in pairs, so as to double on steep hills. During the summer of 1913 a Sauer gasoline truck was successfully operated between the Grand Gulch mine and the east bank of Virgin River, but it was taken off in the fall because of the poor condition of the roads and the cost of keeping up the tires.

WATER.

Between Virgin River and the mine there are three springs. Bitter Spring, on the west side of the Virgin Mountains near the summit, is well named, for its waters are not palatable, though it is said that in the early spring, after the snows, they can be drunk without ill effects.

Willow Springs, at the mouth of Willow Canyon, issues from the deep, partly consolidated conglomerate fill of Grand Wash, where a buried flow of basalt dams the underground water and brings it to the surface.

Pigeon Spring, 8 miles east of the Grand Gulch mine, yields a stream of good water about a quarter of an inch in diameter. It has been developed by pipe and storage reservoirs to supply water for domestic uses at the Grand Gulch mine. All the water is hauled in barrels from the spring to the mine. Pigeon Spring issues below the light-colored limestone cap rock of the second terrace above the Grand Wash.

The Bronze L mine obtains its water supply from a spring near the base of the lower terrace, about three-fourths of a mile north of the mine.

Mud Well is located on the main road, at the summit of the Virgin Range. The waters are heavily charged with mineral and are not good, though used largely for watering the teams. About a quarter of a mile south of the well there is a small marshy area which is called a spring.

Pakoon Well is at the north crossing of the Grand Wash, where "rabbit grass" and mesquite indicate that water is not far distant. At the time of visit there was about 15 inches of water in a box 3 feet square, standing about 5 feet below the surface. It is said, however, that during the summer of 1913 the water here could not always be relied on to fill the radiator tank of the gasoline truck.

CLIMATE.

The climate of this region is typical of the desert country of the Southwest, showing wide daily and yearly ranges. The highest summer temperature is said to be about 105°. The winters are rarely severe, though occasionally the thermometer records a temperature as low as −12° F.

TIMBER.

An open growth of fairly large juniper or "cedar" covers the mesa on which the Grand Gulch and Bronze L mines are located. Interspersed with the cedars are piñon trees, which here and there form small groves. The soil supports a scant cover of desert grass throughout the year. In the spring, after the light snows melt, this growth is said to be luxuriant.

The timbers used at the Grand Gulch mine are obtained from the Shivwits Plateau, 25 miles east of the mine, where there is said to be an open forest of "jack pine" with some "red-pine" trees, some of which are 3 to 4 feet in diameter. This timber, square sawed for mining use and laid down at the mine, is said to cost $30 a thousand feet.

LABOR.

St. George, Utah, 129 miles by road north of Grand Gulch, supplies most of the labor employed at the mine, which is all white. In the fall of 1913 about 50 men were employed by the Grand Gulch Co., most of them at the mine, but some at the lumber camp maintained by the company 25 miles east of the mine. At the Bronze L mine five men were at work.

HISTORY.

According to Mr. Callaway, the Grand Gulch ore deposit was discovered about 1853, though it seems probable that it was known to the Indians before that time. The prospect was bought from the Indians for a horse and some flour by a Mr. Adams, employed by Bishop Snow, of St. George, Utah. Adams patented one claim and located eight adjoining claims. The original claim, the Adams, is patent No. 37. For a number of years the ore was hauled to St. George. In 1870 an adobe smelter was built, which evidently did not meet with marked success, as the small slag dumps have since been shipped for their metal content. An adobe and stone stack now standing near the shaft does not seem to have been used.

After several unsuccessful attempts had been made to operate the Adams mine it was acquired in 1890 by the Jennings brothers, who worked it intermittently for 16 years. Since 1906 it has been a continuous producer. It is impossible to obtain accurate figures of production, though Mr. Callaway estimates the total at $500,000. Since 1906 no ore carrying less than 14 per cent of copper has been shipped. In the fall of 1913 an average of 120 tons of ore was sent to the Salt Lake smelters each month.

The Bronze L mine, formerly known as the Savanic, is controlled by Harry Gentry and Levi Syphus, of St. Thomas, Nev., who took over the property in 1906. It also is an old claim and has had as varied a career as the Grand Gulch. Its production is not known but is probably very much smaller than that of the Grand Gulch mine.

PREVIOUS DESCRIPTIONS.

So far as known there are no published descriptions of the mines of this region, though the presence of the prospects was evidently known to the geologists of the Wheeler Survey, for their position is shown on atlas sheet 66 accompanying the Wheeler reports. The geologic facts concerning this region contained in the preliminary reports of the Wheeler Survey are brought together in part 2 of volume 3 of the final report, issued in 1875. General information on the plateau region is given in C. E. Dutton's "Tertiary history of the Grand Canyon district," issued in 1882 as Monograph II of the United States Geological Survey.

GEOLOGY.

The bold cliffs on the east side of Grand Wash, at the west end of the Colorado Plateau province, as pointed out by Gilbert,[1] lie along a profound fault, which is shown in figure 7. West of this fault zone the sedimentary beds rest in an inclined position along the eastern part of the Virgin Range, dipping at moderately steep angles toward Grand Wash. The wash is from 8 to 12 miles wide where crossed by the road and is filled with coarse, partly consolidated conglomerates and cross-bedded sandstones. The gravels represent two periods of deposition, as is shown near the mouth of Black Canyon, where there is a distinct erosion surface about 30 feet below the top of the gravels. The presence of these two conglomerates was noted by Marvine.[1]

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[1] Gilbert, G. K., U. S. Geog. Surveys W. 100th Mer., vol. 3, p. 54, 1875.

At least two flows of augite basalt are intercalated with the gravel fill. They are confined to the west side of the valley, and the upper flow is at most places thinly covered with gravels. These gravels, in which are interbedded flows, are probably to be correlated with the Temple Bar conglomerate described by Lee.[2] East of the wash the low flat-topped ridges, cut by many canyons, are underlain with soft dull reddish-brown shales and sandstones that are probably part of the lower division of the Redwall limestone.

The great wall forming the east side of the valley is composed of apparently horizontal sedimentary beds of dull-red color. At the base of the cliffs the wagon road turns south behind a ridge composed of westward-dipping limestones similar to the horizontal beds at the east. This fold is local, only a small section of the cliff face about a quarter of a mile long and an eighth of a mile wide showing any disturbed strata. On the line of the road the westward-facing cliff is 1,250 feet high. From its crest the first mesa extends nearly 4 miles eastward and is bounded on the east by a second cliff at least 1,000 feet high. The lower step is composed of alternating beds of dull brownish-red, red, and pink thick-bedded limestones, sandy limestones, and massive cross-bedded calcareous sandstones. The upper step displays, in its lower portion, brilliant red and yellow shales and sandstone, overlying which is a bed of yellowish massive cross-bedded sandstone, capped by light-colored cherty limestone. This succession of rocks can be correlated with the upper half of the section examined at the mouth of the Grand Canyon by G. K. Gilbert. That section, with the changes necessary to make it conform to the stratigraphic nomenclature now in use, is shown in figure 8.

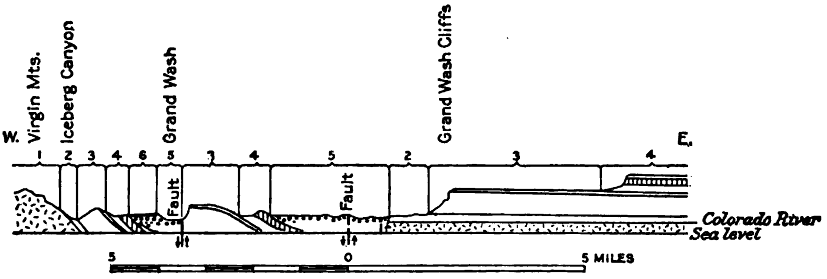

FIGURE 7.—Section of the Grand Wash fault as exhibited by the gorges of the Colorado. Scale 1:150,000. From Wheeler reports, vol. 3, fig. 30, 1875, with changes in geologic names to conform to present classification of United States Geological Survey. 1, Archean; 2, Tonto group; 3, Redwall limestone; 4, Aubrey group; 5, valley fill; 6, basalt.

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[1] Marvine, A. R., U. S. Geog. Surveys W. 100th Mer., vol. 3, p. 197, 1875.

[2] Lee, W. T., Geologic reconnaissance of a part of western Arizona: U. S. Geol. Survey Bull. 352, pp. 17-18, 1908.

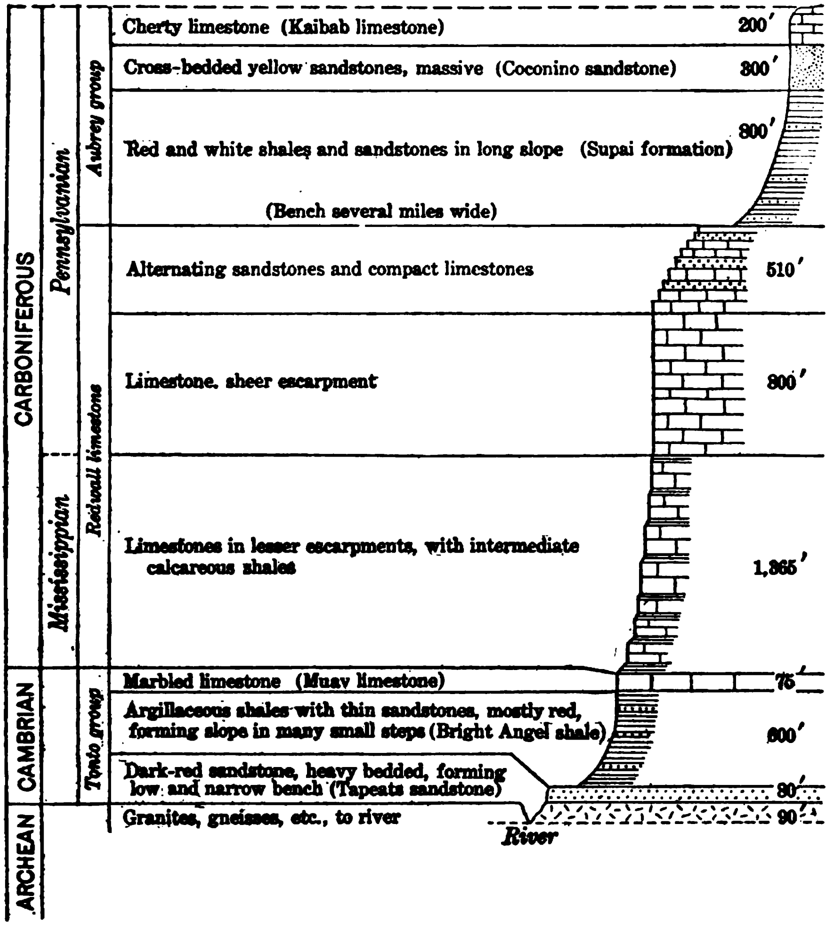
CARBONIFEROUS
CAMBRIAN
ARCHEAN
Pennsylvanian
Mississippian
Aubrey group
Redwall limestone
Tonto group
Cherty limestone (Kaibab limestone) 200′
Cross-bedded yellow sandstones, massive (Coconino sandstone) 300′
Red and white shales and sandstones in long slope (Supai formation) 800′
(Bench several miles wide)
Alternating sandstones and compact limestones 510′
Limestone, sheer escarpment 800′
Limestones in lesser escarpments, with intermediate calcareous shales 1,865′
Marbled limestone (Muav limestone) 75′
Argillaceous shales with thin sandstones, mostly red, forming slope in many small steps (Bright Angel shale) 600′
Dark-red sandstone, heavy bedded, forming low and narrow bench (Tapeats sandstone) 80′
Granites, gneisses, etc., to river 90′
River

FIGURE 8.—Section of the sedimentary series at the mouth of the Grand Canyon. After Gilbert, G. K., op. cit., fig. 82, opp. p. 196.

The following section was measured barometrically by the writer in ascending the road from the base to the summit of the lower cliff:

Section of lower cliff at east side of Grand Gulch, on road between St. Thomas and Grand Gulch mine, beginning at top but 150 feet below the actual rim.

		Feet.
1.	Buff sandstone	50
2.	Pinkish arenaceous limestone	100
3.	Brownish-red sandstone, massive and cross-bedded, grading into arenaceous limestone at top	200
4.	Limestone, fine grained and pink at top, grading into coarse grained and red at bottom	500
5.	Brownish-red sandstone and calcareous sandstone	50
6.	Reddish-white crystalline limestone with some dark-colored cherty beds; grades into sandy lime at top	650
	Base not exposed.	
		1,100

A few fossils were found near the Grand Gulch shaft in the pinkish limestone (No. 2 of the above section), and among them G. H. Girty, of this Survey, determined the following species:

Zaphrentis sp.
Echinocrinus sp.
Productus sp.
Dielasma? sp.
Pugnax utah.
Squamularia perplexa?
Composita subtilita.
Naticopsis? sp.

Mr. Girty says: "This lot is clearly Carboniferous, and though the fossils are very fragmentary and the fauna which they compose is far from diagnostic the geologic age may, with high probability, be assigned to the Pennsylvanian or the Permian."

GRAND GULCH MINE.

EQUIPMENT AND DEVELOPMENT.

Grand Gulch camp lies in a small depression and is not visible from a distance. The first view from the road shows a frame engine house, surrounded by dumps and ore houses, with two long masonry buildings in the background. The shaft is equipped with a 22-horsepower gasoline hoist, whose engine also operates a 10 by 10 inch air compressor capable of running three drills, and with a crosshead and bucket.

From the shaft, which is vertical and 500 feet deep, levels have been run at 100, 200, 300, and 400 feet below the collar. These levels, owing to the peculiar shape of the ore body, presently to be described, are generally of circular plan. At the 100-foot level the ore zone is only a few feet from the shaft. Between the surface and this level there are sublevels in ore at 28, 40, and 60 feet. The 200-foot level has been driven nearly around the circle, though the connection has not been made. On the northwest side of the circle there are four sublevels between the 100 and 200 foot levels, and short sublevels have been driven between these main levels at other places. On the 300-foot level, at the time of visit, a drift around the east and southeast sides of the circle was being pushed to the west at the south side, to connect with an underhand stope in ore on the 200-foot level. On the 400-foot level there is a crosscut to the east and short drifts on the east side of the circle. A station has been cut at the 500-foot level, but no drifting has been done.

GEOLOGIC RELATIONS OF THE ORE BODIES.

The Grand Gulch mine is about a mile and a half east of the mesa rim and a mile north of the deep Pigeon Canyon. In this vicinity the calcareous sandstone forms the surface rock, lying essentially horizontal and covered at most by a few inches of red sandy soil. The shaft is at the head of a small branch of Pigeon Canyon, where the structure is well exposed. There are apparently no faults near the mine, the only fractures being an irregular system of joints.

The ore bodies occur around the sides of a vertical pluglike mass of rock, which is sedimentary but is entirely different from the stratified rocks that inclose it and will in this paper be called the filling. This mass is roughly elliptical in cross section where exposed at the surface over an area about 300 feet long and 180 feet wide. It increases in size to a depth of 250 feet, and from that depth downward it apparently grows smaller, so that on the whole the mass is roughly pear shaped. (See fig. 9.)

The outcrop of the ore is of annular form. To the north and west the croppings are covered by dumps so that details of structure are concealed, but along their northeast side blocks of sandstone for about 4 to 5 feet away from the circular outcrop dip toward the center and are separated from the solid formation by open cracks. Underground no such slumping of the beds was noted. As seen in the mine, the beds end abruptly against the outer wall of the filling. This wall is in some places marked by slickensides, but as a rule is merely a close, irregular surface of separation.

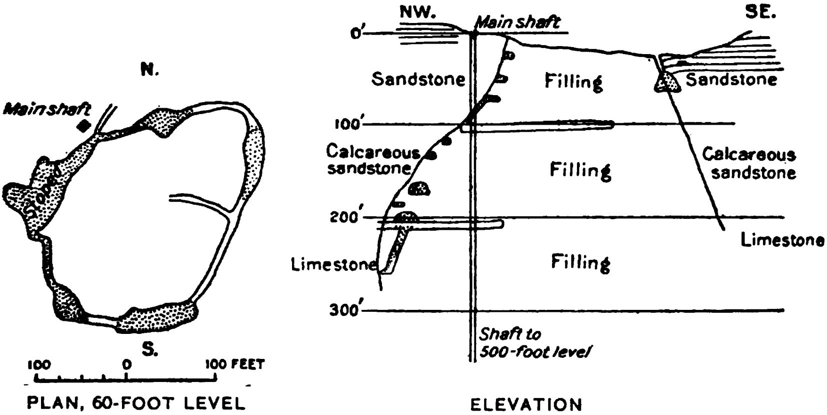

FIGURE 9.—Plan and elevation of the Grand Gulch mine, Mohave County, Ariz.

At the 80-foot level the vertical shaft, whose collar is 40 feet northwest of the ellipse, cuts into the ore zone, which on all sides at this level appears to dip outward. (See elevation, fig. 9.) At the 200-foot level the ore zone is nearly circular in horizontal section and about 300 feet in diameter. It seems fairly well established that below a depth of 250 feet the walls of the ore zone tend to slope inward instead of outward, though the development on the 300 and 400 foot levels is not extensive enough to determine this matter absolutely.

To a depth of 60 feet the inclosing rock is a calcareous sandstone. Below this depth the proportion of lime increases, so that at the 200-foot level the rock is a slightly arenaceous limestone.

The nature of the wall rock below the 400-foot level is not known, but it would seem that this level should be near the top of the massive cross-bedded sandstone that was noted in the section measured along the road up the cliff. (See p. 45.)

The filling is composed of a very fine-grained pinkish-yellow sandstone in which there can occasionally be recognized small pieces of unaltered country rock. As the filling has not proved ore bearing, there are only a few underground openings in which its character could be studied. This rock shows no stratification, so far as noted, for a depth of 500 feet. As seen in thin sections under the microscope it is composed of finely comminuted quartz grains with a very few feldspar grains in a cloudy, slightly ferriferous matrix that contains a considerable quantity of calcite. The explanation here advanced for the origin of the filling is speculative, but is thought to accord with the facts ascertained.

According to Dutton,[1] during Eocene and Miocene time this region was being elevated. There was abundant rainfall, and erosion was rapidly wearing away the younger sediments. The great faults were initiated near the close of the Miocene, effecting differences in elevation of 2,000 to 3,000 feet. The Pliocene he conceives to have been marked by aridity, though the drainage was sufficient to carve out the upper terrace of the Grand Canyon, underlain by Carboniferous rocks, in which the Grand Gulch mine is located. A second upheaval and faulting, amounting to 3,000 to 4,000 feet, he thinks took place at the end of the Pliocene. The inner gorge of the canyon has been cut during this last orogenic movement and in Pleistocene and Recent time.

It is possible that during the periods of denudation at least part of the drainage of this area was subterranean and that the space now occupied by the Grand Gulch filling represents an old sink hole.

Whether the sink hole was formed entirely by solution,[2] or in part by caving of the roof, is not fully demonstrated. The absence of any great number of blocks of rock from the side walls, however, and the small size of those seen, together with the fact that the opening tends to expand more in the easily soluble limestone than in the calcareous sandstone, lead to the conclusion that at least this portion of the channel is the result of solution rather than of caving.

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[1] Dutton, C. E., Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, pp. 208-288, 1882.

[2] Discussions of formations of sink holes will be found in the following papers:

Matson, G. C., and Clapp, F. C., A preliminary report on the geology of Florida, with special reference to the stratigraphy: Florida Geol. Survey Second Ann. Rept., pp. 25-197, 1909.

Matson, G. C., and Sanford, Samuel, Geology and ground waters of Florida: U. S. Geol. Survey Water-Supply Paper 319, pp. 26-28, 1913.

Purdue, A. H., On the origin of limestone sink holes: Science, new ser., vol. 26, pp. 120-122, 1907.

Sellards, E. H., Some sink-hole lakes of north-central Florida: Science, new ser., vol. 23, pp. 289-290, 1906; Origin of sink holes: Idem, vol. 26, p. 417, 1907; Some Florida lakes and lake basins: Florida Geol. Survey Third Ann. Rept., pp. 43-76, 1910.

This sink hole, in consequence of a change in the drainage or a clogging of its outlet, may subsequently have been filled with an unstratified accumulation of fine sandy mud, which by the normal processes of induration would harden into the rock of which the filling is composed.

Mr. Callaway, superintendent of the mine, told the writer that the body had been explained by some as the filling of the vent of a hot spring, and the material is locally referred to as "tufa." This explanation, however, does not seem in harmony with the observed facts. The material, even at its margin, carries none of the minerals characteristic of hot-spring action. Further, there are no accumulations of sinter or travertine anywhere in this vicinity. It is true that such deposits might have been attacked by erosion, but it would seem that some remnants should be found near the orifice of such a spring.

THE ORES.

OCCURRENCE.

At the Grand Gulch mine the ore bodies are distributed all around the outside of the filling, but are not continuous around it at any level, and so far as known there are no ore bodies within the filling. As a rule, the larger bodies appear to be on the northwest and southeast sides. So far as development shows, the ore bodies do not extend below a depth of about 250 feet, no ore having been found on the 300 and 400 foot levels, though what is termed "ledge matter" is opened by the drifts on both of these levels on the east side of the filling.

No other ore bodies have been found in the vicinity of the Grand Gulch mine, except at the Bronze L and at a prospect near it.

The ore bodies are lenslike replacements of portions of the stratified rock in which they lie. The larger ore shoots range in shape from stout irregular pods or lenses, in various attitudes between the horizontal and the vertical, to slender, nearly vertical pipelike bodies.

Between the 200-foot level and the surface there are several large stopes at different points around the circle, which range from 20 to 30 feet in width, 20 to 40 feet in length, and 40 to 60 feet in height. Not all the material removed from these stopes was shipping ore, though much of it that still lies on the dump is said to carry as much as 5 per cent of copper. In these ore bodies the replacement was not everywhere complete and there were probably some inclosed masses of waste. This waste is in some places very soft and sandy, the cementing material having been largely removed, while in other places it is the ordinary unaltered, more or less quartzose limestone.

The ore exposed in these stopes consists largely of malachite, azurite, and brochantite, with small bunches of chalcocite scattered irregularly through it. The carbonate ore, even where it appears to be a solid mass of malachite or azurite, is deceptive, for a varying proportion of the mass is shown by the microscope to consist of quartz grains. In other words, ore of this kind is a replacement of the matrix and of some of the feldspar particles of the original rock, and it is questionable whether any of the original quartz grains were replaced.

The lighter-green ores are apparently all malachite, but certain darker-green and heavier ores, particularly near masses of chalcocite, contain brochantite, a basic copper sulphate, mixed with carbonate. A very little light bluish-green chrysocolla is present in some varieties of the ore. The blue ores are apparently all azurite, part of which has been formed from malachite, while some of it appears to have replaced the matrix of the rock directly.

Some of the bodies of carbonate ore are, with little question, formed from the direct alteration of chalcocite in place, but others, in places where there is not a particle of the sulphide, are believed to have been deposited as such from solutions which may have obtained their copper from a higher part of the ore zone, perhaps from portions that have since been eroded away.

Where chalcocite occurs in the carbonate ore bodies, very few sand grains, if any, are inclosed by it. One thin section of chalcocite ore appears to show that the copper sulphide replaces the quartz, the replacement starting from the edges of the grains or from cracks through them. A specimen of chalcocite from the carbonate bodies was found to contain veinlets of a nearly white, waxy mineral which on polished faces appears slightly pinkish gray and has a nonmetallic luster. This mineral is soft and brittle. Chemical tests show it to contain lead, chlorine, and some carbonate. The carbonate, however, is thought to be in the form of malachite, which, in one of the thin sections, is seen to be replacing the chloride mineral. The gray mineral is probably cotunnite. In the alteration of chalcocite, malachite appears to form first, and subsequently it changes to azurite. It is possible, however, that the chalcocite first alters to brochantite and that this mineral then alters very quickly to malachite. Both minerals occur with chalcocite, but no definite zone of the sulphate between the sulphide and carbonate was seen.

The most interesting ore bodies in the mine were those stoped between the 100 and 200 foot levels, at the northwest side of the circle, in the Pancake, Slap Jack, and Hot Cake stopes, situated 15, 27, and 39 feet, respectively, above the 200-foot level. In these stopes the ore occurred as thin horizontal layers parallel to the bedding of the limestone. The Pancake stope extends for 300 feet around the circle, and the workable ore in it was from 20 to 30 feet wide and from 3 inches to 3 feet thick. The Slap Jack stope is 20 by 40 feet in horizontal dimensions, and the ore in it was 2½ to 3 feet thick. The Hot Cake stope was 100 feet long and averaged 40 feet in width, and the ore in it was apparently 2 feet thick. The floor of the Pancake stope is flat, but the roof is irregular in detail. In the Slap Jack stope both the floor and roof are relatively smooth, and in the Hot Cake stope the roof is smooth and the floor is irregular.

The ore has been removed from these stopes except in a very few pillars and along the edges, where it is too thin to mine. In all these stopes the larger part of the ore is said to have consisted of massive chalcocite, though a little malachite and azurite are present at both the upper and under surfaces and are seen lining vugs and fractures in the chalcocite.

These chalcocite bodies apparently occur along beds of arenaceous limestone in which the proportion of sand to lime is less than in the adjoining beds. Locally the replacement is not entirely complete, and small portions of the mass carry a considerable quantity of sand grains; elsewhere the replacement has been complete and the chalcocite mass is nearly pure, containing only a little malachite along cracks. Under the microscope polished faces of the chalcocite show interlocking intergrowths of very small crystals. Some microscopic bands through the chalcocite show a crystalline structure resembling that of comb quartz. Other polished sections show radiating growths of chalcocite crystals. Blowpipe tests indicate that this chalcocite contains no lead or silver.

Limonite is present in the carbonate ore bodies and is the only metallic mineral found on the 300 and 400 foot levels, where it occurs as thin coatings along open crevices and in the matrix of the arenaceous limestone.

ORE MINERALS.

The following minerals, identified in part by W. T. Schaller, of this Survey, were found in ores from the Grand Gulch mine collected by the writer:

Azurite, $(CuOH)_2.Cu(CO_3)_2$; dark blue. Occurs as a replacement of the matrix of calcareous sandstone and arenaceous limestone in the Grand Gulch mine.

Brochantite, $CuSO_4.3Cu(OH)_2$; dark green. Occurs intimately mixed with malachite in the darker-green ores, especially near bodies of altering chalcocite. Has not been separated from the carbonate, but its presence is shown in the dark-green ore by the test for sulphate.

Chalcocite, Cu_2S; black. Metallic. Occurs as remnants in masses of carbonate ore and was found practically pure in the flat stopes near the 200-foot level on the northwest side of the circle.

Chrysocolla, $CuSiO_3.2H_2O$; light bluish green. Occurs in small quantities in the lower-grade ore from the carbonate stopes. Replaces the matrix of sandstones.

Cotunnite, $PbCl_2$; white, waxy. Occurs as a replacement of chalcocite in a specimen collected on the dump. It is seen in minute branching veinlets cutting the chalcocite, from which it may be distinguished by a pinkish tone on polished surfaces; also has a nonmetallic luster. This mineral is not pure, as it in turn is being replaced by malachite. It may be phosgenite, $(PbCl)_2.CO_3$, though it is thought that the carbonate found in the tests came from the malachite.

Cuprodescloizite, yellowish. A specimen collected on the dump shows a thin greenish-yellow crystalline coating along joints of pinkish arenaceous limestone. W. T. Schaller has found lead, copper, and vanadium to be present in this coating, but it does not contain uranium.

Malachite, $(CuOH)_2.CO_3$; green. Occurs as a replacement of the matrix of calcareous limestone and arenaceous sandstone, as an alteration product from chalcocite and from the cotunnite. Is the most prevalent ore mineral in the mine.

Limonite, $(Fe_4O_3.(OH)_6$; dull brownish. Occurs below the 250-foot level in the ore zone, also more or less widely scattered throughout the ore bodies.

Mr. Callaway reports that he has seen chalcopyrite and bornite in minute grains in the chalcocite ore, but neither of these sulphides was observed by the writer.

ORIGIN OF THE ORES.

The apparent failure of the copper ores to extend much below a depth of 250 feet, though the pervious ledge matter extends below that depth, leads to the belief that they were deposited by downward-moving waters. That these waters were probably cold seems to be rather well demonstrated by the absence of any hydrothermal alteration of the wall rocks in the vicinity of the deposit.

The sulphide ores in the flat stopes may have originally been chalcopyrite and bornite. If this was the case, these iron-bearing copper sulphides have been almost completely replaced by or altered to chalcocite, which was the only sulphide seen by the writer in those stopes, though small quantities of chalcopyrite and bornite are said to have been found in them. The masses of carbonate are in the larger lenses around the filling are thought to be in part secondary after copper sulphides deposited in those localities, and in part formed by direct deposition of the carbonates from solutions that derived their copper content from higher portions of the ore body.

It is considered probable that the present ore bodies have been formed by the gradual downward movement of the ore materials along this cylindrical channel as the surface was eroded. The absence of ores in the filling is to be explained by the fact that this filling is only slightly if at all pervious to water. In the mine it is everywhere dry, while at the 300-foot level outside of the ore zone there is a suggestion of moisture along some of the bedding planes of the limestone.

The deposition of the ore probably did not begin until after the consolidation of the filling. If the waters that were present at the time the filling was deposited had carried copper in solution, it would seem that this copper should have been precipitated by the lime carbonate and kaolin which are so abundant in the mud. As a matter of fact, there is not the slightest suggestion of any copper mineralization in the filling.

The origin of the iron, present as limonite in minor amounts in the copper carbonate stopes and in somewhat larger quantities on the 300 and 400 foot levels, is not entirely clear. It may have been derived from chalcopyrite and bornite that may have been present in the sulphide ore bodies on their alteration to chalcocite. Iron-bearing copper sulphides are certainly not now abundant. If these sulphides were present and were altered to chalcocite, their iron content would account for the limonite in the mine. The iron may possibly have been derived from the ferruginous coloring matter of the strata which once covered the terrace and are now seen in the cliffs east of the mine.

CONCLUSIONS.

So far as developments have demonstrated, the ore at the Grand Gulch mine does not extend below a depth of about 250 feet. The ledge matter, apparently as porous as in the upper levels, continues below the known ore bodies. The question arises, May this portion of the ore zone be a barren leached zone, and is it possible that at greater depth other ore bodies will be found?

The ore zone at the Grand Gulch mine below the known ore bodies contains some limonite, but so far as seen there were no copper minerals of any kind on either the 300 or the 400 foot level. It would seem that if this were a leached zone, there should be traces of copper carbonates left, or the material should have a pitted texture indicative of the former presence of sulphides. No such indications were noted by the writer.

According to the explanation of the origin of this deposit advanced in the preceding pages, all the metals were brought to their present positions by generally downward-moving waters. If the amount of copper carried by these solutions was comparatively small, as it is thought to have been, it is possible that all of the copper may have been taken from them and deposited in the first 250 feet of their descent.

BRONZE L MINE.

DEVELOPMENT AND ECONOMIC FEATURES.

The Bronze L mine, 3 miles south-southwest of the Grand Gulch mine, is developed by a shaft said to be 200 feet deep, which has caved a short distance below the 100-foot level. The shaft is an incline to the southeast at an angle of 60°, and there are drifts about 100 feet long on the 60 and 100 foot levels. Hoisting is done by a bucket and whim.

The collar of the shaft is 500 feet below the top of the mesa, in a steep-walled ravine which opens northward into Pigeon Canyon near its mouth. (See fig. 6.) A road half a mile long from the mine to the mesa is rather steep, so that in the fall of 1913 burros were used to carry the ore that distance. It is said, however, that with little additional expenditure a wagon road, already partly built, could be completed to the Grand Wash. This would shorten the haul about 13 miles and would reduce the climb about 1,700 feet.

THE ORES.

OCCURRENCE.

The mine lies near the middle of the more arenaceous member (No. 4 of the section on p. 45) of the beds forming this terrace. The sandstones are somewhat calcareous throughout, and some beds are decidedly limy.

The ore bodies are closely related to a rather tight fissure zone which strikes N. 45° E. and dips 60° SE. In some places along this zone the ore occurs as small lenses connected by stringers. There are also stringers and small flat kidneys of ore parallel to the horizontally bedded sediments. One bed of very dense reddish sandstone with some calcareous cement exposed at the 60-foot level, 100 feet southwest of the shaft, has been fractured and is seamed with veinlets of sulphide for at least 18 feet from the fissure zone.

On the 100-foot level, about 75 feet northeast of the shaft, a 10-foot crosscut extends southward into a 4-foot zone of fracturing which strikes N. 20° W. and stands vertical. There is some carbonate ore on the small angular fragments in this zone.

ORE MINERALS.

The ore minerals are largely sulphides, with smaller amounts of azurite and malachite derived from their alteration. A specimen of ore obtained from the southwest drift at the 60-foot level shows the series of alteration from chalcopyrite and bornite, through chalcocite, to the carbonates. The chalcopyrite apparently first alters to bornite, which usually surrounds the remaining kernels of the yellow iron-bearing sulphide. In places, however, remnants of chalcopyrite are inclosed in chalcocite without the intervening band of bornite. The bornite is replaced by or alters to chalcocite, which in turn is seamed by veinlets of a mixture of copper-pitch ore and copper carbonates. (See fig. 10.) In his use of the term "copper-pitch ore" the writer follows Lindgren,[1] who applies it to "a dark-brown to black substance, sometimes dull, but generally with glassy to resinous luster, hardness about 4, streak dark brown." The name as used probably covers a series of obscure minerals containing oxides of copper, manganese, and iron, with silica and locally other constituents.

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[1] Lindgren, Waldemar, Copper deposits of the Clifton-Morenci district, Arizona: U. S. Geol. Survey Prof. Paper 43, pp. 114-115, 1905.

Microscopic examination of polished sections indicates that most of the bornite has been formed secondarily at the expense of the chalcopyrite, but some of it may be primary. All the secondary chalcocite appears to be crystalline, as shown by etching a polished surface with nitric acid. The etched surfaces are similar in appearance to those of chalcocite ore from the Grand Gulch mine, which, while thought to be primary as regards other minerals in that deposit, is probably of supergene origin. This is contrary to the opinion expressed by Graton and Murdoch,[1] that "secondary" chalcocite is not crystalline, though they say that in some places it shows a system of cleavage lines inherited from bornite, and usually an irregular system of cracks which are "the outlines of individual grains."

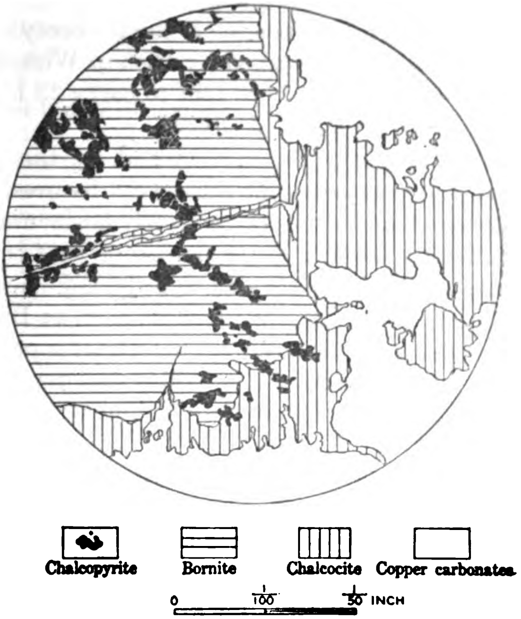

FIGURE 10.—Camera lucida drawing of a polished section of ore from the Bronze L mine, Bentley district, Mohave County, Ariz., showing the steps of alteration of chalcopyrite and bornite through chalcocite to the copper carbonates.

ORIGIN OF THE ORES.

These ores are believed to have been deposited by atmospheric waters along the more or less open fissure zone. Whether the waters moved in a downward or a lateral direction was not determined, though it is thought that the original deposition was effected under reducing influences, and that the carbonates now present were all derived later from the original sulphides. The opinion has been advanced that the Bronze L is a deposit similar in character to that of the Grand Gulch. The fissure, it is true, is slightly curved, but the rocks on each side are the same, and there is no indication of the former existence of a sink hole.

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[1] Graton, L. C., and Murdoch, Joseph, The sulphide ores of copper; some results of microscopic study: Am. Inst. Min. Eng. Bull. 77, pp. 760-765, 767, May, 1913.

PROSPECTS.

Three-quarters of a mile south of the Bronze L mine there are a few shallow shafts and pits on a northeasterly fissure containing some chalcocite and copper carbonate ore. The mode of occurrence is similar to that at the Bronze L mine.

COPPER KING MINE.

The Copper King mine is situated about 40 miles east of the Grand Gulch mine, at Copper Mountain, on the Kanab Plateau. The mine is 3 miles north of Colorado River, on the rim of the Grand Canyon, and there is said to be an abundance of water in springs 8 miles distant. A small spring a quarter of a mile from the camp supplies 20 gallons a day. This mine is the property of John A. Swapp, of Overton, but is being worked by Bishop Whitehead, who ships every two months a carload of ore said to carry 23 to 26 per cent of copper and from $3 to $4 a ton in silver.

This property was not visited by the writer. He was informed that the ores occur in northwest fissures, which dip steeply to the southwest and cut approximately horizontal sedimentary rocks. The ore bodies are in a white sandstone that is covered by a light-colored limestone. They are said to be lenslike bodies connected by stringers of good ore. The ore minerals seen at Bishop Whitehead's store at Overton are chalcopyrite, chalcocite, copper-pitch ore, cuprite, malachite, and azurite. Mr. Whitehead reports, however, that cerusite and calamine are sometimes found in open watercourses through the other ore.

A specimen given to the writer by Bishop Whitehead shows remnants of chalcopyrite altering directly to copper-pitch ore, which in turn is altering to cuprite and carbonates. This material is covered with botryoidal layers of limonite and malachite, with a final coating of beautiful green feltlike masses of malachite.

BIBLIOGRAPHY OF COPPER ORES OF THE "RED BEDS."

A review of the literature shows that the preponderance of evidence leads to the conclusion that the copper ores occurring in the "Red Beds" of the Western States are epigenetic and have been deposited by atmospheric waters moving generally downward. The original source of the copper is not definitely known. The metal is thought to have been deposited in Triassic and Jurassic (?) sediments, in part as detrital material from older copper-bearing deposits and in part by solutions which had derived the copper from such older deposits. It is fairly well established that the copper of the present deposits was widely desseminated in the sediments and that it was gathered and brought to its present position by cold waters charged with chlorides and sulphates.[1]

The copper was probably carried as a sulphate and was deposited as a sulphide by natural reducing agents such as carbonaceous matter and also by calcareous or kaolinic cementing materials. Ransome[2] has lately proposed the term "supergene" to designate "minerals deposited by generally downward moving initially cold solutions."

The following list includes the more important publications on the deposits of copper in the "Red Beds" of the Western States:

Blandy, John F., An Arizona copper deposit: Eng. and Min. Jour., vol. 64, p. 97, 1897. Describes a deposit of copper and iron sulphide 50 miles north of Williams, near the rim of the Grand Canyon.

Cazin, F. M. F., New Mexico v. Lake Superior as a copper producer: Eng. and Min. Jour., vol. 30, p. 87, 1880. Describes copper deposits of the Nacimiento Mountains, N. Mex., as carbonates and silicates of copper largely replacing plant remains and impregnating marls and as pebbles in conglomerate.

Emmons, S. F., Copper in the Red Beds of the Colorado Plateau region: U. S. Geol. Survey Bull. 260, pp. 221–232, 1905. Summarizes existing reports on "Red Beds" deposits and describes a deposit on the Grand View trail, 12 miles east of the Bright Angel trail, in the Redwall limestone. The ores are copper carbonate and chrysocolla, with chalcocite in the center of the larger masses. Pyrite and chalcopyrite are occasionally found. Ores occur along a shear zone. Also mentions occurrence in Unaweep Valley, 15 miles south of Grand Junction, Colo.

Emmons, W. H., The Cashin mine, Montrose County, Colo.: U. S. Geol. Survey Bull. 285, pp. 125, 129, 1906. States that the ores occur along a fissure in La Plata (Jurassic) sandstone, where covellite, chalcocite, bornite, native copper, malachite, azurite, cuprite, and iron sulphate are found disseminated in the crushed zone. Thinks that the ores were leached down from above.

Fleck, Herman, and Haldane, W. G., A study of the uranium and vanadium belts of southern Colorado: Colorado Bur. Mines Rept. for 1905–6, pp. 80–81, 1907. Discusses green cupriferous sandstone in southwestern Colorado.

Gale, H. S., Geology of the copper deposits near Montpelier, Bear Lake County, Idaho: U. S. Geol. Survey Bull. 430, pp. 112–122, 1910. Describes some copper deposits in the "Red Beds" (Triassic). Malachite and azurite occur in joints and bedding planes of a somewhat calcareous sandstone and in shales. Chalcocite and covellite at depth replace wood fiber.

Herrick, C. L., The occurrence of copper and lead in the San Andreas and Caballo Mountains: Am. Geologist, vol. 22, pp. 286–291, 1898. Describes copper deposits of the San Andreas Mountains, N. Mex., as occurring in a bed of red sandstone which lies at the contact of granite and overlying Carboniferous sediments and which carries hematite, chalcocite, malachite, and cuprite.

Hill, J. M., Copper deposits of the White Mesa district, Arizona: U. S. Geol. Survey Bull. 540, pp. 159–163, 1914. Describes some copper deposits on the White Mesa, 145 miles north of Flagstaff, Coconino County, Ariz., in rocks which are probably to be correlated with the La Plata sandstone of southwestern Colorado.

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[1] Lindgren, Waldemar, The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 79, 1910; Mineral deposits, pp. 375–376, New York, 1913.

[2] Ransome, F. L., Copper deposits near Superior, Ariz.: U. S. Geol. Survey Bull. 540, p. 153, 1914.

Jennings, E. P., The copper deposits of the Kaibab Plateau, Ariz.: Am. Inst. Min. Eng. Trans., vol. 34, p. 839, 1904. Describes the replacement deposits on the Kaibab Plateau in the vicinity of Jacobs Lake, which occur in the "Aubrey" (Carboniferous) limestone, now known as Kaibab limestone.

Jones, F. A., Mines and minerals of New Mexico, 1904. Describes the copper ores in the "Red Beds" of New Mexico.

Lindgren, Waldemar, Notes on copper deposits in Chaffee, Fremont, and Jefferson counties, Colo.: U. S. Geol. Survey Bull. 340, pp. 170–174, 1908. Describes the occurrence of copper carbonate and chalcocite in "Red Beds" at Red Gulch, Fremont County, Colo.

——— Mineral deposits, New York, 1913. On pages 368–382 discusses the foreign and American deposits of copper, lead, vanadium, and uranium in sandstone and shale and states that the epigenetic character of such deposits is proved beyond reasonable doubt.

Lindgren, Waldemar, and Graton, L. C., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, pp. 76–79, 1910. Conclude from a study of the copper deposits in sandstones in New Mexico that they are of epigenetic origin, formed by the replacement of carbonaceous, kaolinitic, and calcareous material of the sandstone by chalcocite, through the action of atmospheric waters charged with chlorides and sulphates.

Lunt, H. F., The copper deposits of the Kaibab Plateau, Ariz.: Am. Inst. Min. Eng. Trans., vol. 34, p. 989, 1904. In discussing paper by E. P. Jennings, mentions the somewhat similar deposits on the White Mesa north of Flagstaff.

Newberry, J. S., Geological report: Exploring expedition from Santa Fe, N. Mex., to the junction of the Grand and Green rivers * * * in 1859, p. 117, 1876. Describes copper ores in the Nacimiento Mountains, N. Mex., as copper carbonates in light-colored sandstones containing plentiful plant remains.

Peters, E. D., Notes on the Oscura copper fields and other mines in New Mexico: Eng. and Min. Jour., vol. 34, p. 270, 1882. Describes copper deposits in the Sierra Oscura, N. Mex., which occur in deformed Permian sediments.

Schmitz, E. J., Copper ores in the Permian of Texas: Am. Inst. Min. Eng. Trans., vol. 26, pp. 97–108 (see also pp. 1051–1052), 1896. Describes copper deposits in flat-lying red beds along the valleys of Red and Brazos rivers, northern Texas.

Tarr, W. A., Copper in the "Red Beds" of Oklahoma: Econ. Geology, vol. 5, pp. 221–226, 1910.

Turner, H. W., The copper deposits of the Sierra Oscura, N. Mex.: Am. Inst. Min. Eng. Trans., vol. 33, pp. 678–681, 1903. Describes copper deposits which occur in deformed shales and sandstones of Permian (?) age. Ores are copper glance and carbonate in minute grains disseminated through the rock and in nodular masses with a kernel of chalcopyrite, bornite, and chalcocite replacing plant remains.

Russell Gibson
~~R A Crawford~~

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 580—E

A NEW GYPSUM DEPOSIT IN IOWA

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BY

GEORGE F. KAY

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1913, PART I—E

WASHINGTON
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1914

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
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A NEW GYPSUM DEPOSIT IN IOWA.[1]

By **George F. Kay.**

INTRODUCTION.

For many years Iowa has ranked among the important gypsum-producing States of the United States. The deposits from which all the output has come are in Webster County, in the vicinity of Fort Dodge, where an area comprising more than 40 square miles may be regarded as available for gypsum mining. The gypsum is confined to a single bed, which is practically horizontal and ranges in thickness from 10 to 25 feet. A mantle of drift 60 to 80 feet thick covers the gypsum except along Des Moines River and its tributaries. The deposit and the related rocks are probably of Permian age.[2]

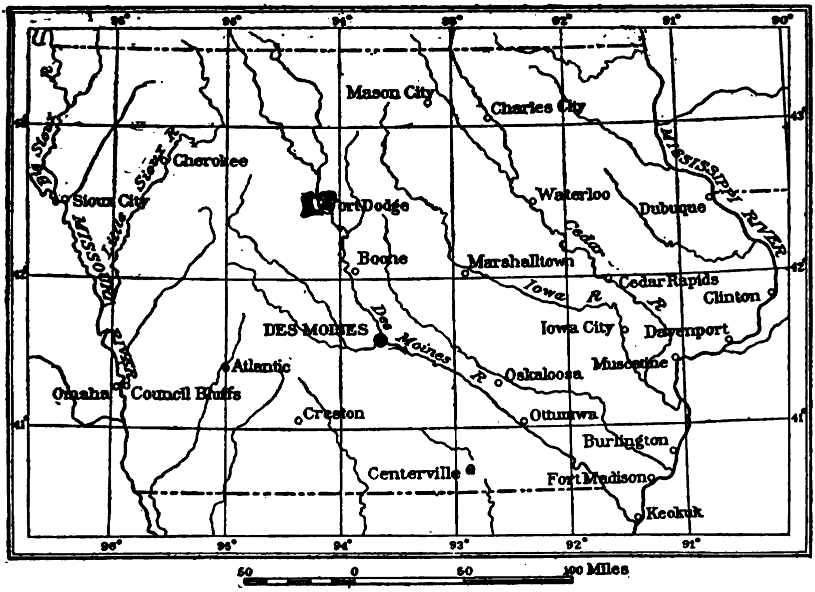

Figure 11.—Index map showing location of gypsum area at Centerville, Appanoose County, Iowa, and its relation to the gypsum area of Fort Dodge.

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[1] A brief reference was made to this deposit in Iowa Geol. Survey Ann. Rept., vol. 21, p. 24.

[2] Geology of Webster County: Iowa Geol. Survey Ann. Rept., vol. 12, pp. 111–114.

A new gypsum deposit was recently discovered in the southern part of the town of Centerville, Appanoose County, Iowa. For many years the Scandinavian Coal Co. has been operating a coal mine at Centerville. In the fall of 1910 this company decided to do some additional prospecting for coal on its property by means of the diamond drill. Accordingly, a contract was made with a Chicago firm for not less than 550 feet of drilling, either as separate holes or as one hole. Although the coal bed worked by the company lies only about 100 feet below the surface and although the base of the coal-bearing strata in this region, as shown by artesian-well records, lies considerably less than 550 feet below the surface, the company, nevertheless, directed the drillers to carry out the contract by continuing a hole to the depth of 550 feet. By means of this drilling gypsum was discovered below the coal-bearing rocks.

GEOLOGY OF THE REGION.

Kansan drift of variable thickness overlies the indurated rocks throughout Appanoose County, except in the deeper valleys, where the drift has been eroded and the underlying rocks have been exposed. The rocks just beneath the drift belong to the Des Moines group, of the Pennsylvanian series. The upper part of the Des Moines contains the Mystic coal bed, which is one of the most persistent and extensively developed coal beds in Iowa. This coal and related bands of limestone of wide extent, some of which lie above the coal and some below, were designated by Bain the Appanoose formation,[1] to distinguish them from the underlying, more typical shaly phase of the Des Moines of Iowa, the rocks of which are very irregular in thickness and in lithologic character and include several beds of coal that are in places thicker than the Mystic bed but are of moderate extent.

To the south of Appanoose County, in Putnam County, northern Missouri, the Pennsylvanian rocks are similar to those of Appanoose County. In accordance with the classification of the Pennsylvanian series of the eastern part of Putnam County, recently published by the Missouri Geological Survey in cooperation with the United States Geological Survey, the indurated rocks of the Centerville region belong to the Henrietta formation and the Cherokee shale, the Mystic (Lexington) coal being in the Cherokee a few feet below the base or "cap rock limestone" (Fort Scott limestone member) of the Henrietta formation.

The rocks below the Pennsylvanian in Appanoose County are known only from drill records of artesian wells. At Centerville three deep wells have been sunk for water. The deepest of these wells and the one of which there is the most complete record gave a section as follows:[2]

---

[1] Bain, H. F., Geology of Appanoose County: Iowa Geol. Survey Ann. Rept., vol. 5, pp. 373-394.

[2] Iowa Geol. Survey Ann. Rept., vol. 21, p. 935.

Record of deep well at Centerville, Iowa.

	Feet.
Quaternary: Drift	90
Carboniferous:	
Pennsylvanian: Shales, coal and coaly shale, and a few thin seams of limestone	436
Mississippian: Chiefly limestones and shales	574
Devonian: Limestone and shales	260
Silurian: Limestones, shales, and sandstones	180
Ordovician: Dolomites, limestones, sandstones, and shales	955

The depth of this well was 2,495 feet. Its bottom penetrated the Oneota dolomite, or lowest formation of the Ordovician in Iowa. This well was sunk in 1893, and if gypsum was penetrated it was not so recorded by the drillers. However, in this connection, it is of interest to state that the log of one of the other deep wells,[1] completed in 1904, contains a statement to the effect that at a depth of 600 feet below the surface the drill passed through 15 feet of "white sand." From the evidence that has been obtained from the holes recently drilled it is very probable that this material should have been recorded as gypsum. This well is more than half a mile northeast of the hole in which gypsum was first recognized.

The driller's log of the Scandinavian Coal Co.'s hole in which the gypsum was first recognized is given below.

Driller's log of hole of Scandinavian Coal Co., Centerville, Iowa.

	Thickness.		Depth.			Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*		*Ft.*	*in.*	*Ft.*	*in.*
Filled ground	3	0	3	0	Limestone	4	0	216	0
Yellow clay	28	0	31	0	Black shale	9	2	225	2
Limestone	1	0	32	0	Coal		10	226	0
Limestone with shale	8	0	40	0	Fire clay	1	0	227	0
Soft blue shale (banded)	10	0	50	0	Clay shale	2	0	229	0
Soft blue shale	14	0	64	0	Soft blue shale	3	0	232	0
Limestone	3	0	67	0	Soft clay shale, gray	1	6	233	6
Sandy shale [a]	21	0	88	0	Blue shale	3	6	237	0
Old workings	4	0	92	0	Black shale	1	4	238	4
Fire clay	2	0	94	0	Soft clay shale, gray		8	239	0
Limestone	1	6	95	6	Blue shale	3	0	242	0
Soft clay shale	1	6	97	0	Blue shale with bands of red shale	1	6	243	6
Dark shale	9	0	106	0	Blue shale	3	8	247	2
Gray shale	7	0	113	0	Black shale	4	6	251	8
Fossiliferous shale	1	0	114	0	Coal	1	8	253	4
Black shale	3	0	117	0	Black shale		8	254	0
Gray shale, very soft	2	0	119	0	Gray shale	6	0	260	0
Gray shale	13	0	132	0	Black shale	4	0	264	0
Black shale	2	6	134	6	Clay shale	8	0	272	0
Soft clay shale	15	6	150	0	Gray shale	13	0	285	0
Shaly sandstone	38	0	188	0	Sandy shale	4	6	289	6
Sandstone	1	0	189	0	Sandstone	2	6	292	0
Black shale	2	0	191	0	Black shale	2	0	294	0
Coal		2	191	2	Blue shale	6	0	300	0
Gray shale	8	2	199	4	Gray shale	5	0	305	0
Black shale		8	200	0	Sand shale	2	0	307	0
Coal	1	0	201	0	Red and blue shale	8	6	315	6
Limestone	1	6	202	6	Blue shale	4	6	320	0
Soft clay shale	7	6	210	0	Black shale	6	0	320	6
Clay shale		10	210	10	Gray shale	3	9	324	8
Limestone	2	0	212	10	Black shale	1	0	325	3
Black shale	2	10	215	8					

[a] The driller's logs of holes 2 and 3 show no shale on top of the old workings of the Mystic bed; the roof is limestone.

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[1] Iowa Geol. Survey Ann. Rept., vol. 21, p. 937.

Driller's log of hole of Scandinavian Coal Co., Centerville, Iowa—Continued.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Coal		2	325	5
Black shale		6	325	11
Sandy shale	15	3	341	2
Coal	1	5	342	7
Sandy shale	4	5	347	0
Sandstone	5	0	352	0
Gray shale	3	9	355	9
Black shale	2	9	358	6
Gray shale	6	0	364	6
Dark shale	2	6	367	0
Gray shale	5	0	372	0
Black shale	9	0	381	0
Sandstone	7	0	388	0
Sandy shale	2	0	390	0
Black shale	3	0	393	0
Gray shale	12	6	405	6
Black shale		10	406	4
Coal (A)		8	407	0
Gray shale	4	0	411	0
Blue shale	4	0	415	0
Coal (B)		3	415	3
Blue shale	3	9	419	0
Clay shale	2	0	421	0
Gray shale	6	0	427	0
Red and gray shale	2	0	429	0
Gray shale	1	0	430	0
Clay shale	2	0	432	0
Gray shale	7	0	439	0
Shaly limestone	6	0	445	0
Limestone	14	0	459	0
Lime shale	9	6	468	6
Sandstone	8	6	477	0
Limestone		6	477	6
Lime shale	6	6	484	0
Limestone	16	0	500	0
Conglomeration of sand and limestone	6	0	506	0
Limestone with spots of shale	17	0	523	0
Limestone	14	0	537	0
Anhydrite, compact	5	0	542	0
Gypsum, white, crystalline	5	0	547	0
Limestone, dolomitic, buff	2	3	549	3
Green shale		9	550	0

This log has been interpreted as follows:

Correlation of log of Scandinavian Coal Co.'s hole at Centerville, Iowa.

	Feet.
Quaternary: Drift	31
Carboniferous:	
Pennsylvanian: Des Moines group:	
Henrietta formation: Limestones and soft blue shales	36
Cherokee shale: Blue, gray, and black shale, sandstone, several thin seams of coal, and some limestone	372
Mississippian: Chiefly limestone, lime shale, shaly limestone, some sandstone, gypsum and anhydrite	111
	550

The gypsum and anhydrite were penetrated between the depths of 537 feet and 547 feet below the surface. Analyses made under the direction of Dr. S. W. Beyer, Iowa State College, proved that the upper 5 feet of this 10 feet was anhydrite and the lower 5 feet gypsum. The gypsum was overlain by 14 feet of limestone and underlain by 2 to 3 feet of buff dolomitic limestone, beneath which was shale.

DEVELOPMENT.

Soon after gypsum had been found in Discovery hole some of the citizens of Centerville subscribed sufficient funds to drill two additional holes. One of these was located 1,200 feet southwest of Discovery hole at a lower elevation. The drill penetrated to a depth of 563 feet but found neither gypsum nor anhydrite. The Mississippian was pierced to a depth of 114 feet, the hole ending in shale, above which was 2 feet 6 inches of dolomite.

A third hole was then drilled about 1,700 feet northwest of Discovery hole. This hole gave a section upon which the following interpretation is placed:

Correlation of log of third hole at Centerville, Iowa.

	Feet.
Quaternary: Drift	20
Carboniferous:	
Pennsylvanian: Gray, blue, and dark shale with seams of coal and limestone	456
Mississippian: Limestone, arenaceous limestone, some sandstone, and gypsum	116
	592

The gypsum was entered at 572 feet below the surface. It proved to be 19 feet thick and of fine quality. Just beneath the gypsum was gray sandy shale, which was penetrated for only 1 foot.

The Centerville Gypsum Co. was then formed, with a capitalization of $25,000, and decided to sink a shaft close to Discovery hole with the object of using it later for hoisting gypsum on a commercial scale. This shaft was started about July 1, 1912. The gypsum was reached about September 1, 1913, and since that time the shaft has been sunk to the rock beneath the gypsum. The shaft is 16 by 6 feet and has three compartments. Gypsum, 13 feet in thickness, was reached at a depth of 533 feet. In the eastern part of the shaft the gypsum is free from anhydrite, but in the western part anhydrite is associated with the gypsum.

When the shaft reached a depth of 528 feet, only a few feet above the gypsum, progress was greatly hampered by large quantities of artesian water that entered it. Some water had come in nearer the surface, but it was easily handled. The artesian water, about 3,300 gallons an hour, comes from a porous limestone about 4 feet thick which lies on the gypsum. It rises to a height of about 300 feet. The problem of handling this water has not been solved. A large deep-well pump, capable of handling 8,000 gallons of water an hour, has been installed, and it is hoped that the water, though a great handicap to development, will not prove impossible to control. It is the purpose of the company, if it finds that the gypsum can be mined on a large scale, to erect a modern plant for the preparation of gypsum products such as are now being made at Fort Dodge.

THE GYPSUM.

The gypsum that has been obtained from the 2-inch drill cores and from the shaft is of two fairly distinct varieties, rock gypsum and selenite. The rock gypsum breaks into irregular-shaped lumps, is white in color, and is composed of small, brightly shining elongated crystals. It is saccharoidal and distinctly friable, being easily crumbled to fragments resembling a pure-white granulated sugar. Much of the selenite is very clear and transparent with the characteristic pinacoidal cleavage. It is possible to secure fairly large masses of selenite free from impurities. Some of the selenite is gray to light brown in color.

Under the direction of Dr. S. W. Beyer, of the Iowa State College, five analyses were made, two of the gypsum and three of the anhydrite. The results[1] were as follows:

Analyses of gypsum and anhydrite from Appanoose County, Iowa.

	Gypsum.		Anhydrite.		
	1	2	1	2	3
Sulphur trioxide (SO_3)	46.56	45.65	54.12	55.29	54.45
Lime (CaO)	33.37	32.76	40.20	40.67	39.58
Loss on ignition	20.03	20.75	6.62	4.66	5.13
	99.96	99.16	100.94	100.62	98.16

SUMMARY.

The discovery of a deposit of gypsum in the Mississippian rocks of southern Iowa is of scientific interest. Whether or not this gypsum will prove to be of economic importance has yet to be determined. The evidence indicates that the deposit may be extensive and the gypsum is of good quality. The presence of anhydrite decreases the value of the deposit for making wall plaster and related products. The relation of the anhydrite to the gypsum and the relative amounts of the two minerals will have an important bearing on the commercial value of the deposit. However, anhydrite is considered by some manufacturers of Portland cement to be practically as serviceable as gypsum.

The fact that the deposit is more than 500 feet below the surface and the presence of large amounts of artesian water are factors unfavorable to the mining of the gypsum. On the other hand, the deposit is well located with regard to fuel and transportation, and it is fair to assume that if gypsum products were made in this part of the State a good market for such products could soon be developed.

---

[1] Iowa Geol. Survey Ann. Rept., vol. 21, p. 24.

R D Crawford

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 580—F

SOME DEPOSITS OF MICA IN THE UNITED STATES

BY

DOUGLAS B. STERRETT

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SOME DEPOSITS OF MICA IN THE UNITED STATES.

By Douglas B. Sterrett.

INTRODUCTION.

This paper is intended to present descriptions of a number of mica deposits examined in various parts of the United States during the summer of 1913. It has not been prepared with any idea of attaining completeness, either for the whole United States or for any of the States in which mines were examined, but describes only those deposits which could be reached in the time available. General information on the production, value, uses, and nature of mica is given only very briefly.

Much assistance was kindly rendered by many persons during the examination of different mines and is here acknowledged. Aid was given in New Hampshire by Samuel Cordick, superintendent of the General Electric Co.'s mine; Andrew T. Orr, of the Mica Products Co.; C. W. Bryant, of the Standard mine; L. R. Brown, of Canaan; G. N. Ricker, of Canaan, who furnished general information on a number of mines in Grafton County and extended other kindnesses; M. M. Kilton, of Grafton Center; L. L. Howard, of the Keene Mica Products Co.; W. A. French, of the American Insulator & Mica Co.; Leon Allen, of Keene; and Edward Howard, of East Alstead; in Virginia by P. Lippert and Capt. McCray, of the Ridgeway Mica Co., and several persons owning mica prospects near Axton; in North Carolina by George H. Hauser, of Winston-Salem; in South Carolina by Earle Sloan, formerly State geologist; R. C. Willimon, of Greenville; and J. J. Fretwell, of Anderson; in Texas by George Kirtley and Mr. Elerding, of the Texas Mica Co.; and in Colorado by J. D. Endicott, of Canon City; B. H. Bigger, of Morrison; and Messrs. Kitchens, of Masonville. Other persons helped with many little kindnesses.

The production of partly trimmed sheet mica in the United States in 1912 amounted to 845,483 pounds, valued at $282,823, and the production of scrap mica amounted to 3,226 short tons, valued at $49,073, a total value of $331,896. In 1913 the value of the production exceeded $400,000. The price of mica varies greatly according to the quality and the uses to which the mica is to be put. It is also subject to considerable variations due to market conditions.

Very little of the mica mined can not be used in some way, but some of it, known as scrap and suitable only for grinding, may bring as low as $10 to $15 a ton. From these figures the price ranges to more than $1,000 a ton for large sheet mica. The average price paid for run of mine mica, not split or sorted, ranges from $50 to $200 a ton. During part of 1913 a prominent mica company offered the following prices per pound for rough trimmed sheet mica of good quality guaranteed to cut into plates of the sizes indicated:

To punch disks 1½ inches in diameter	$0.03½
To cut sheets 1½ by 2 inches	.12
2 by 2 inches	.30
2 by 3 inches	.70
3 by 4 inches	1.35
4 by 6 inches	2.25
6 by 8 inches	4.00

Specked and clay-stained mica may bring less than half these prices, and mica of exceptionally good grade would command higher prices.

Mica is used in various industries, such as the manufacture of electric machinery, stoves, certain forms of lamp chimneys, fireproof materials, wall papers, and lubricants. The perfect insulating qualities of mica and the adaptability of its sheets to various forms of manufacture render it unsurpassed for use in electric apparatus. By fitting together and cementing with shellac many small thin sheets, mica is built up into large sheets of "micanite," or "mica board," which are suitable for many forms of electric insulation. The transparency, flexibility, and resistance to heat of mica are qualities that make it particularly suitable for use in stove windows and lamp chimneys. Ground mica is used to impart a silvery luster to wall paper and for other decorative effects. It is also mixed with oils and grease for lubricating. Ground mica mixed with shellac, called "molded mica," is used in electric insulators of various types.

CHARACTERISTICS OF MICA.

Of the several varieties of mica only two, muscovite and phlogopite, have extensive application in the industrial world. Only muscovite is mined in the United States.

Muscovite, like all the other micas, belongs to the monoclinic system of crystallization but has a symmetry approximating the hexagonal. This symmetry is indicated by nearly hexagonal outlines observed in the prisms, by the percussion figures, and by "ruled" and "A" mica.

Mica mined for commercial purposes is generally found in rough blocks, sometimes with an irregular development of crystal faces. The faces are not usually as many as would be required to complete the simplest crystal, and their surfaces are generally very rough. Very commonly a large part if not all of a block of mica has a ragged outline without plane surfaces. Fairly well developed hexagonal or rhombic prisms are occasionally observed in crystals of mica weighing hundreds of pounds.

Rough crystals, or "books" of mica, as they are called in the Western States, do not split perfectly until the outer shell of etched and partly crushed mica has been removed. This is accomplished by rough splitting or cleaving the large book into sheets one-sixteenth inch thick or less and trimming the edges with a knife held at a small angle with the cleavage. Further splitting is then easy, because the cleavage of mica is so perfect and the tangled outside edges of the sheets have been removed. By grinding a wedge edge on the sheets and using a thin, sharp knife mica can be readily split into sheets as thin as one one-thousandth of an inch.

A percussion figure is formed by three cracks or cleavages in a plate of mica crossing at a common point and making angles of approximately 60° with one another, commonly described as a six-rayed star. It may be produced by striking a sheet of mica a sharp blow with a pointed punch or thrusting the punch through the sheet.

Mica has a number of physical peculiarities which give rise to different trade names and descriptive terms used by the miners. These are due to crystal structure, color, and inclusions. Structural peculiarities give "ruled" or "ribbon," "wedge," "A," "hair-lined," "fishbone" or "herringbone," and "tangle-sheet" mica. Trade names for different colors of mica are "rum," "ruby," "amber," "white," and "black." Brown, green, and greenish-brown colors also occur in mica. Certain inclusions give "specked" and "clay-stained" mica. Most of these characteristics are well known to users of mica or can be readily recognized when first encountered.

Muscovite is sometimes called white mica, in allusion to its high transparency when split into thin sheets. In such sheets very little if any color is visible, but the same mica may show a strong color in sheets one-sixteenth of an inch or more thick, and it is to these thicker sheets that reference is made in describing the color of mica in the following pages.

Mica from different deposits, either in the same or in different States, may show wide variations in quality. It is not possible to assign certain constant qualities to mica from any one State which has a number of mines in intermittent operation. Accordingly accurate comparisons can not generally be made between the output from the several producing States. Mica of variable quality is found in nearly every region where more than one deposit is worked.

GENERAL GEOLOGY.

Most of the mica deposits of the United States occur in regions of highly metamorphic gneisses and schists. A few have been found in less altered granites or other igneous rocks. The highly metamorphic gneisses and schists are considered to be of pre-Cambrian age in most places, but in others the age has not been determined.

Deposits of muscovite mica of commercial value are confined to pegmatite. This rock is variable in composition, but in its more normal phases is composed of feldspar and quartz, with or without mica and other minerals. It is therefore allied to granite in composition and has been called giant granite. Its texture grades from that of ordinary granite to that in which the individual grains or minerals measure a number of feet across, and both these extremes may be found in the same deposit.

Orthoclase and microcline are the most common varieties of feldspar found in pegmatite. In many places, however, a variety of plagioclase, either albite or oligoclase, makes up part or all of the feldspar component. The feldspar occurs in masses and rough crystals, some of which may be several feet thick.

Quartz occurs in several ways in pegmatite—either intermixed with feldspar and mica in granitic texture, or graphically intergrown with feldspar, or segregated out into large separate masses. The segregated quartz may form sheets or veins in the interior or along the walls, or it may occur in irregularly shaped bodies through the pegmatite. It is massive and generally granular, though locally showing rough crystallization.

The mica is found in various positions in the pegmatite and no definite rule can be laid down for guidance in finding it in different deposits. In the pegmatites in which quartz segregations are prominent the mica is generally richest near the quartz. In some deposits the mica follows one or the other wall, and in others it may be either regularly or irregularly distributed through the pegmatite. The mica occurs in rough crystals and blocks, which range is diameter from a small fraction of an inch to several feet. The rough blocks, as obtained from the mines, generally yield only a small percentage of trimmed sheet mica, a yield of 10 per cent being unusually high. The remaining mica is suitable only for grinding.

Pegmatites occur in irregular masses, sheets, and lenses, which range in size from small deposits to those many yards in thickness and length. These masses cut the country rock, either conformably with its bedding or at various angles to it. Some pegmatites are conformable with the bedding of the inclosing gneisses or schists through part of their extent and cut across it in other places. The irregularities in the shape of pegmatite deposits render their mining difficult.

NEW HAMPSHIRE.

HISTORY OF MICA MINING.

Mica mining in the United States began with the opening of the Ruggles mine in Grafton County, N. H., about 1803. Later other mines were opened in New Hampshire, which for many years furnished practically all the mica used in the United States. Mining was carried on in a desultory way until about 1840, and then operations became extensive until 1860. After 1868, when mica mining commenced in North Carolina, the production in New Hampshire declined, and in the last 40 or 50 years it has only intermittently formed a considerable part of the total production in the United States. Large imports and large outputs of mica from other States have several times so reduced the price of mica as to nearly make its mining unprofitable in New Hampshire. During the last three years there has been a revival in mica mining in this State, and the production for 1913 was larger than for a number of preceding years.

Most of the New Hampshire mica mines have been worked intermittently, and some of them have been operated on a large scale. New mines of value are still being discovered and some of the old mines are opened at intervals with varying results. The dumps of some of the old mines have been worked over for the smaller sizes of sheet mica and the scrap mica thrown away during earlier mining. The yield of mica from such operations has been large.

The mines described below are only those examined during part of June, 1913. A number of large and well-known mica mines of New Hampshire are not included simply because it was not possible to visit them in the time available. The descriptions include several mines not in operation as well as those being worked at the time of examination. Some of the descriptions are very incomplete, as the mines were in such a condition that details could not be learned, or sufficient time was not available for complete study.

Mica deposits have been mined in Grafton, Cheshire, Sullivan, Merrimack, Strafford, and Coos counties. The best deposits lie in a belt (probably a broken belt) extending from Keene through the middle of Cheshire County northward into Sullivan County and the northwestern part of Merrimack County and east of north to about the center of Grafton County. The principal mining districts in this belt are in the towns of Rumney, Groton, Alexandria, Orange, and Grafton. There are also a few mines in Dorchester and Canaan, Grafton County; Danbury and Wilmot, Merrimack County; Springfield and Acworth, Sullivan County; and Alstead, Gilsum, and Sullivan, Cheshire County. The shipping points have been Rumney, West Rumney (now Swainsboro railway station), Bristol, Canaan, Grafton Center (now Cardigan railway station), Grafton, Danbury, and Keene.

GENERAL FEATURES OF OCCURRENCE.

The mica deposits of this region lie in broken mountain country at elevations ranging from less than 1,000 to over 3,000 feet above sea level. Swampy areas, ponds, and lakes, characteristic of glaciated regions, occur in unexpected places among the hills. Much of the country is rather thickly covered with second-growth timber and brush. The roads away from the main lines of travel are bad or indifferent, so that some of the mines are not easily accessible. The abandonment of many of the farms in the mica region is responsible for the poor condition of the roads and for the heavy growth of brush now mantling large areas of the country. This desertion of the farms also works another hardship on the mica industry, making it difficult for the miners to find boarding places or for the companies to purchase food and forage for the camps.

The rocks of the mica region of New Hampshire are complex and consist of a series of metamorphic schists and gneisses with intruded granite and pegmatite. The mica deposits are not confined to any one definite type of rock. Hitchcock[1] states that mica deposits of value are to be found chiefly in an area of fibrolite-mica schist, a subdivision of the "Montalban group" as mapped in his "Geologic atlas of New Hampshire." Many of the largest mines are located in areas of this rock, but some valuable mines are included in areas of rock mapped under different names.

For practical purposes the rock with which the mica-bearing pegmatites are associated may be called mica gneiss. This rock, which is evidently of great age, includes highly metamorphosed schists and gneisses of various types, such as biotite and muscovite schist and gneiss, with some layers rich in quartz or containing black tourmaline, garnets, etc. In places the gneiss is porphyritic.

GRAFTON COUNTY.

General Electric Co.'s mine.—A new deposit of mica half a mile west of Swainsboro (formerly called West Rumney) was opened two years ago by the General Electric Co., of Schenectady, N. Y. This deposit is on the Burley estate and had been known for several years. The pegmatite is exposed through a short distance only, so that there had been much hesitancy by prospective buyers about purchasing the property until it was finally taken up by the General Electric Co. This company set up a shop and storage house near the mine and has equipped a building near by with the best modern power machinery for the first steps in manufacturing the mica on a large scale. The plant can also be utilized in preparing mica that may be obtained from other mines in the region owned by the company or from other producers.

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[1] Hitchcock, C. H., Geology of New Hampshire, vol. 3, pt. 5, pp. 89-91, 1878.

The mine is located near the top of a small hill about 60 feet above the valley on the south side. The position of the workings and surrounding features is shown in the rough sketch forming figure 12. The work consists of an open cut or stope 50 feet long in a N. 60° E. direction, 55 feet deep on an average incline of about 60° NW., and of varying width. The mine is about 50 feet higher than the terrace ground below.

The country rock is mica gneiss. Near the pegmatite it consists of a highly foliated quartz-biotite-muscovite gneiss. Fibrolite, if present, is not conspicuous. The gneiss has been strongly folded near the mine and strikes from N. 60° E. with high northwest dip to north with 70° E. dip. The pegmatite is in part conformable with the inclosing gneiss, having an average strike of N. 60° E. and dip of 60° NW. through the 100 feet where it has been exposed by stripping of the hillside soil. If the pegmatite holds this strike to the southwest for more than 100 feet it could be opened at a level nearly 50 feet lower. A prospect trench in the position shown in the sketch would determine this point. The width of the vein exposed in the working averages about 8 feet but varies from 18 feet at the surface to 4 feet in the bottom at the northeast end. Variations in thickness occur where there are rolls or pinches in the wall rock. About 150 feet due east of the mine a mass of pegmatite several feet thick outcrops on the hillside. This might be the same vein warped from the strike shown in the workings, or it may be another body of rock.

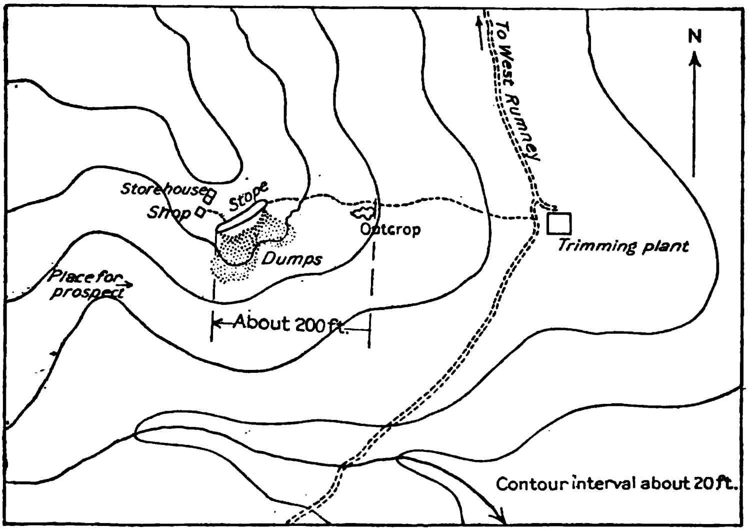

FIGURE 12.—Rough sketch of General Electric Co.'s mica mine near Swainsboro, Grafton County, N. H.

The pegmatite has a varied texture, some being very coarse grained and some resembling coarse granite. In places along the contacts where the texture is not coarse there is a partial banding of mica-rich streaks with mixed quartz and feldspar. The vein is richest in mica along the hanging wall for a thickness of 1 to 3 feet, but bunches or pockets of good mica also occur scattered through the mass of the pegmatite. The mica crystals range from small ones to some 2 feet or more in diameter. Much of the mica is in clean crystals with good, flat cleavage. It has a clear light rum color, and the best sheets make an excellent stove mica. Fragments of beryl crystals 2 to 6 inches in diameter were observed on the dump. These crystals are reported to range from 6 to 12 inches in length.

The pegmatite in the outcrop between the mine and trimming plant is coarse grained. It contains large masses of quartz with some mica and should be prospected.

Palermo mine.—The Palermo mica mine (formerly called Hartford) is about 1½ miles southwest of North Groton, in one of the ridges on the northeast side of Bald Head Mountain. This mine is one of those noted large producers of mica of which several have been worked extensively in New Hampshire. It is now said to be owned by the General Electric Co. No work was in progress at the time of examination and many of the workings were filled with water. The following description has been prepared from a study of the dumps and workings still open and from information kindly furnished by Mr. L. R. Brown, of Canaan. Mr. Brown was superintendent for nearly 20 years when the mine was in operation.

The workings available for examination are described below: An open cut (1, fig. 13) 100 feet long, 40 feet deep in the end, and 20 to 30 feet wide, is driven N. 10° W. into a steep hillside. (See fig. 13.) At the end of the cut there is a large tunnel or room (2, fig. 13) 50 feet long with deep inclined stopes from it; an upraise (3) connects with workings about 30 feet higher and to the west, where an open cut (4) 30 feet long has been made, with drifts and stopes carried underground on the pegmatite. Another open cut (5) 20 to 30 feet wide and 40 feet long had been made to the northeast of the main working, and about 50 feet higher than the main cut. From this an inclined shaft (6) was sunk, and according to Mr. Brown this shaft connected with one of the main stopes of the mine at considerable depth. Water filled the workings to the level of the main open cut. Several large dumps have been built up to the south and west of the mine and cover more than 2 acres of ground. Iron rail tracks lead to the later dumps from the deep stopes at the end of the open cut. Several of the buildings have collapsed, and all are in a bad state of repair. A thick growth of brush and saplings conceals much of the dumps and the area around the mine. Parts of the dumps have been worked over for small sheet and scrap mica thrown away during earlier operations. These dumps are probably not more than half worked over and will still yield a quantity of small sheet and scrap mica.

The following information was supplied by Mr. Brown, who states that the inclines with stopes sunk from the room at the end of the main cut are very extensive. Three inclines were sunk in about the position shown in figure 13 to depths of more than 300 feet. The vein (7, fig. 13) between these inclines was stoped out in large masses, pillars being left where necessary. The inclines were steep, probably at least 45°, and were equipped with tracks and mine cars raised by the hoisting engine in the end of the main open cut. The mine did not require a great amount of pumping when the quantity of ground opened is taken into consideration. One stope was nearly 30 feet high and 60 feet long, representing a huge pocket of almost solid mica. Most of the work was done by single-hand drills. At one time 85 miners were employed and 25 to 30 girls were kept busy sorting and trimming mica.

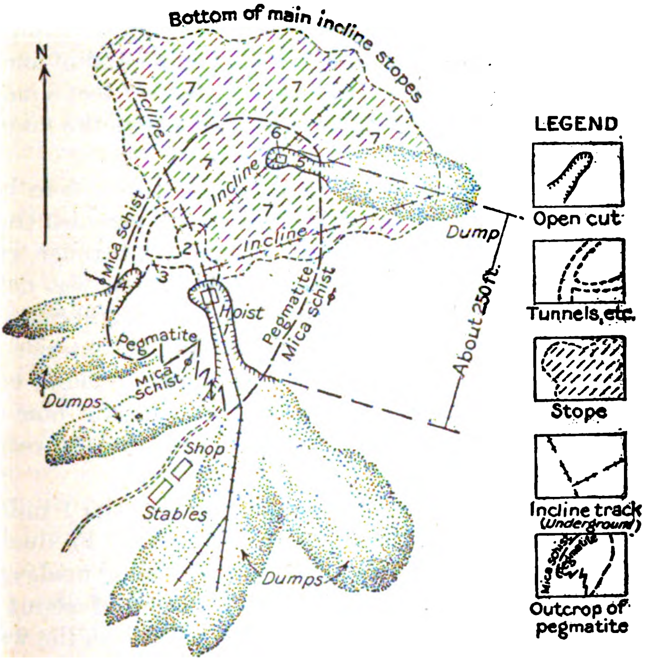

FIGURE 13.—Plan of Palermo mica mine, near North Groton, Grafton County, N. H. See text for explanation of numbers.

The country rock is a lumpy or porphyritic biotite schist or gneiss, in which the lumps appear to be composed almost entirely of bunches of muscovite mica. The strike of this rock, measured near the mine, varies through wide limits, owing to distortion during intrusion of the pegmatite. The pegmatite cut across the country rock in a large, irregularly shaped mass, whose approximate outcrop is shown in figure 13. This outcrop indicates an oval or pipe-shaped deposit, but from the information furnished by Mr. Brown and incorporated in the sketch the pegmatite appears to spread out as either a curved sheet or a conical mass underground. Owing to the resistant qualities of the rock the outcrop forms a small knob on the end of a ridge. The texture of the pegmatite is diverse, and in places extremely coarse. Feldspar occurs in crystals and masses several feet across, and some of the irregular quartz segregations are large. In places the rock carries much small mica mixed with feldspar and quartz. Large mica is reported to have been found proportionally rich in pockets through the vein. Mr. Brown tells of one mica crystal found which measured 4 feet 2 inches long and 28 inches wide, and of another fine crystal with sharp edges and fairly smooth faces 2 feet square and 2 feet thick. The mica left in the dumps shows that the mine yielded a clear, rum-colored mica of good quality.

Among interesting specimens found on the dump were beryl and zinnwaldite mica. The beryl ranged from small greenish translucent crystals to opaque crystals 3 inches across. One rough crystal of mica less than an inch across, found on the dump, was determined to be zinnwaldite by W. T. Schaller, of the Geological Survey. The sheets of this mica show a clear brown core and an exterior of bluish green, about the color of indicolite tourmaline. These colors are arranged parallel to lines of crystallization and the blue contains thin zonal growths of the brown. Both parts give the reactions of zinnwaldite.

Mica Products Co.'s mine.—Two new mica deposits 1 mile west of North Groton were opened during 1913 by the Mica Products Co., of Philadelphia. At one of these an open cut was being made extending southwestward into a steep hillside for a height of about 45 feet. The cut was carried back into the hillside by benches, the waste rock being rolled to the bottom and carried off in mine cars to the dump.

The country rock is mica gneiss, in places carrying fibrolite. It is cut by pegmatite, striking N. 48° E. and dipping about 80° NW. The pegmatite ranges from 8 to 16 feet in thickness, with an average of over 12 feet. The mica is richest near the middle of the vein, but some is scattered through other parts. Much of the mica is rather small but of fine stove quality. It is of a beautiful clear rum color in sheets one-tenth of an inch thick. One crystal was found that weighed 24½ pounds and would cut into sheets over 6 inches square.

The other deposit lies a couple of hundred yards north, and was being prospected by small cuts in an outcrop of hard pegmatite about 50 feet wide. The pegmatite is inclosed in mica gneiss or schist, and has a strike of N. 45° E. and a vertical dip. The mica obtained here has been exposed to the weather and is not as sound as that from the other working. It might be found to improve with depth, if present in sufficient quantity to pay for development. Pale-green beryl crystals were found, parts of which were clear enough for gems.

India Mica Co.'s mine.—The India Mica Co.'s mine is in the southeast corner of the town of Dorchester, near Bryant Pond, about 5¾ miles N. 40° E. of Canaan. The mine was closed in 1906, after several years of active operation. It had good equipment in the way of camp, engines, and machinery. Two principal openings were made, an open cut 70 feet long and 20 feet deep north of the engine house and a cut 50 feet long opening into a stope 50 feet deep south of the engine house. (See fig. 14.) Pillars were left in this stope and five tiers of floors were built, with stulls and lagging. An inclined track extended from the engine house down into the stope for the removal of mica and waste rock.

The country rock is quartz-biotite schist which strikes N. 20°–35° E. and has a steep west to vertical dip. Near the pegmatite the schist contains much black tourmaline in small crystals. The pegmatite is approximately conformable with the inclosing schist. In the north working the formations have been kinked or folded, as shown by the shape of the open cut (fig. 14). The pegmatite is in the main from 6 to 10 feet thick, and the entire thickness was removed in mining at the southwest end of the mine. At the surface the pegmatite bulges to 12 feet in thickness, but is poor in mica. At 50 feet below the surface the vein, it is reported, pinches down to 12 inches in thickness. The texture of the pegmatite appears to be rather even. The feldspar is mostly oligoclase and was not found in very coarse crystals. The mica has a clear light rum color and some of it is of good quality. It occurs in crystals, some of which weigh 50 pounds. In the folded part of the pegmatite many of the mica crystals are twisted and of poor quality.

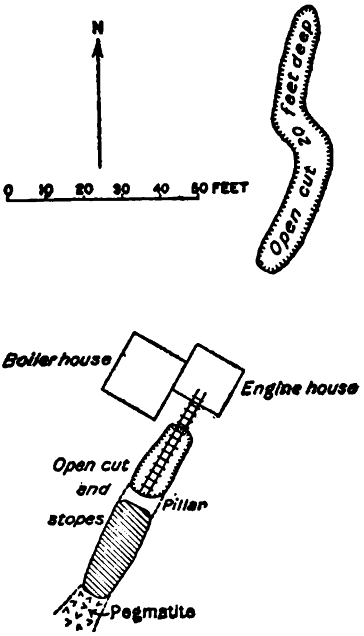

FIGURE 14.—Plan of India Mica Co.'s mine, in the southeast corner of the town of Dorchester, Grafton County, N. H.

Two hundred yards west of north of the mine a prospect was opened on an outcrop of pegmatite 15 feet thick. Mica, mostly small, was found associated with large segregations of quartz. Black tourmaline is also present in the pegmatite.

During the earlier days of mining by the India Mica Co. the mica as it came from the mine was hauled to Canaan and there graded for shipment. Later a plant was set up in Canaan and the mica was rough trimmed for the market.

Keyes mine.—The Keyes mica mine is 4¾ miles N. 50° E. of Canaan, in the town of Orange, on the east side of the north end of Tugg Mountain. The principal working was an open cut of about the shape shown in the rough plan in figure 15, and 5 to 18 feet deep. Most of the open cut was in pegmatite, but streaks or horses of the biotite mica gneiss country rock were encountered at the places shown. The full thickness of the pegmatite was not exposed, but is probably at least 50 feet with the mica gneiss inclusions. One large horse of gneiss is 10 feet thick, but does not extend far into the pegmatite, as shown in the cross section (fig. 15). The inclusions all strike northeast, which is probably also the trend of the pegmatite. The texture of the pegmatite is coarse in places, the feldspar crystals measuring a foot or two across. The mica is somewhat pocketed and appears to be richest near the contact with the mica gneiss. At the bottom and on the west side of the large horse of mica gneiss good mica has been left in the pegmatite. The mica has a clear light-rum color and some of it is of good quality. The pegmatite carries beryl, pieces of which were seen on the dump, and one crystal 8 inches across had been left in the rock. A few rough quartz crystals were removed during mining, but most of the quartz is massive.

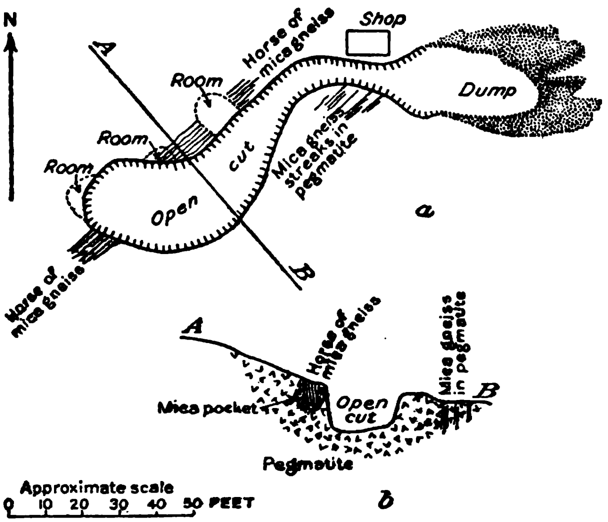

FIGURE 15.—Plan and cross section of Keyes mica mine, 4¾ miles northeast of Canaan, Grafton County, N. H., showing workings and part of geology.

Sanborn mine.—The Sanborn mica mine is on Tugg Mountain, about 3½ miles N. 70° E. of Canaan. It has not been operated for three years. The developments consist of an open cut of the shape shown in figure 16. This cut is about 100 feet long, with an enlargement at the south end, and is 10 to 20 feet deep. The country rock is a highly foliated mica gneiss with quartzose and micaceous layers. Both biotite and muscovite are present. The gneiss strikes N. 10°–20° E. and has a high dip to the east. Several beds of pegmatite, whose surfaces have been rounded by glacial erosion, outcrop on the summit of the hill. These pegmatites are in part conformable with the inclosing gneiss, but in places cut across its bedding. The mica has been obtained from a small bed of pegmatite about 10 feet thick, which has branched out from a large mass of pegmatite into the surrounding gneiss and from around the end of the body of mica gneiss included between the fork and the main mass of the pegmatite. The inclosed body of gneiss is about 60 feet thick and at the south end the contact has a pitch to the north of about 35°. The cross section in figure 16 shows the relations between the pegmatite and gneiss. The pegmatite has an uneven texture and in places contains quartz segregations. More mica is exposed in the outcrop south of the open cut near the contact of the pegmatite at a place where the mica gneiss has been crumpled by folding. The mica seen around the mine was of fair quality, some having a clear rum color and some a slightly greenish cast.

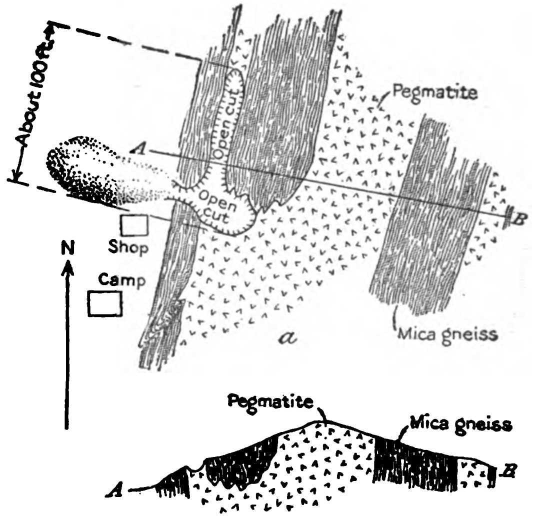

FIGURE 16.—Plan and cross section of Sanborn mica mine, 3½ miles N. 70° E. of Canaan, Grafton County, N. H., showing geology and workings.

Belden or Standard mine.—The Belden or Standard mine is on the south end of Tugg Mountain, 3 miles N. 75° E. of Canaan. It has been operated by several persons and companies, and worked by the Standard Mica Co. on an extensive scale. The last work was done by C. W. Bryant, of Lebanon, in June, 1913. At this time the mine consisted of an irregular-shaped open cut or quarry about 250 feet long in a north-south direction, about 200 feet wide, and from 10 to 45 feet deep. Another smaller open cut had been made to the south of the main quarry. The approximate position of the openings, mine buildings, tracks, dumps, etc., is shown in the rough sketch in figure 17. The quarry was worked to different levels in benches, as shown in the figure. At the south end of the main quarry two short tunnels were made.

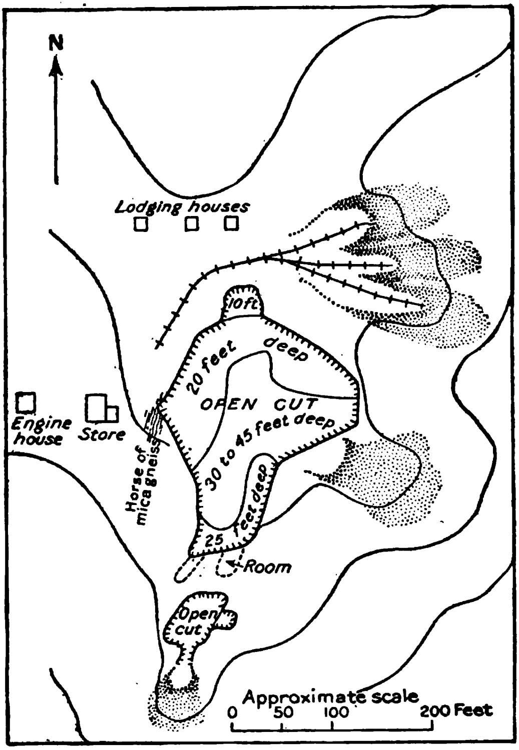

FIGURE 17.—Plan of workings at Belden or Standard mica mine, 3 miles N. 75° E. of Canaan, Grafton County, N. H.

The country rock is mica gneiss composed of quartzose layers and layers rich in biotite and muscovite. The pegmatite is a very large mass whose relation to the country rock is not exposed. The impression gained by examination of the workings is that of a thick bed with a northerly strike and a dip of 20°–30° E., but it is possible that the dip is more nearly vertical. The open cut is wholly in pegmatite except for a small horse of mica gneiss on the west side. This gneiss has been strongly metamorphosed and contains a quantity of black tourmaline. It appears to merge into the pegmatite. The pegmatite varies in texture and in places is very coarse. Feldspar crystals 1 to 3 feet thick were seen, and quartz occurs in irregular segregations and veins, in one place 7 feet thick. Beryl crystals are rather common, and the mica and beryl are most plentiful around the quartz masses. In general the mica is rather pockety, but a few crystals occur scattered through the pegmatite, and to insure the recovery of all this mica the whole of the pegmatite was mined by the Standard Mica Co. This proved to be an extravagant method. The later work by Mr. Bryant was directed only toward those parts of the pegmatite found to be richest in mica.

The pegmatite is composed of two kinds of feldspar, microcline and albite. In places the microcline has formed a rough graphic intergrowth with quartz. Some of the albite occurs in rough crystals, almost of the clevelandite type. Black tourmaline is scattered through the pegmatite with small quantities of bluish-green apatite and opaque garnets. The beryl crystals range from small ones to some 10 inches in diameter and 12 inches long. Probably several tons of rough opaque crystals could be gathered up around the mine. Most of the mica is small, under 4 by 6 inches, but sheets 8 by 10 inches are reported to have been cut from the largest crystals. The mica is of fair quality, showing shades of both rum and green colors.

Other mica prospects have been tested on the same property, one 150 yards southwest, another about 300 yards southwest, and another 250 yards north-northwest of the main mine. At the first of these the pegmatite is at least 40 feet across and carries a quantity of small mica. Along the west contact of the pegmatite the gneissic wall rock merges into the pegmatite as if by a fusion contact. At the second place an open cut 50 feet long was made on a pegmatite vein 2½ to 6 feet thick, and another cut 45 feet long on another vein 1 to 4 feet thick, lying 60 feet to the west. These pegmatites are in part conformable with the inclosing gneiss, but one of them has a branch or fork cutting across the foliation.

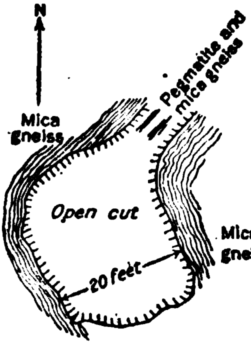

FIGURE 18.—Plan of Hoyt Hill mica mine, 3 miles S. 75° E. of Canaan, Grafton County, N. H.

Hoyt Hill mine.—The Hoyt Hill mine is 3 miles S. 75° E. of Canaan, near the summit on the west side of Hoyt Hill. The working consists of an open cut or shaft 20 feet across and reported to be about 50 feet deep, inclined to the north. It was filled with water at the time of examination, and only surface conditions could be studied. The country rock is mica gneiss composed of biotite and muscovite schists with quartzose layers. Black tourmaline is present in some of the layers. The schist layers of the gneiss are in places strongly folded and crumpled and inclose lenses and streaks of quartz, pegmatite, and granite. The strike is N. 30°–40° E. and the dip is rather variable. The pegmatite cuts through the gneiss in the form of a stock or pipe. The plan of the open cut in figure 18 shows the approximate shape of the deposit. On the northeast side the pegmatite forks out into the gneiss. On the east side the gneiss has been crumpled by the intrusion of the pegmatite. Among the minerals observed on the dump were pinkish plagioclase feldspar, black tourmaline, and green apatite. The mica has a clear rum color, and crystals of good size are said to have been obtained.

Prospect near Orange.—A mica deposit was worked on the road from Orange to Alexandria, about 3½ miles east of Canaan and half a mile southeast of Orange. Two open cuts and a short tunnel were made in the position shown in figure 19. The cut near the road is reported to have been 30 feet deep, but is now filled up. The one to the north is about 15 feet deep, but is at present filled with water. The country rock is mica gneiss containing streaks of fine biotite schist. It strikes N. 10° E., and stands vertical. The pegmatite is irregular in shape and was not found in the northern open cut in line with the strike shown by the work near the road. Black tourmaline is plentiful in the pegmatite and occurs in crystals 4 inches in diameter. Very little mica had been left around the mine.

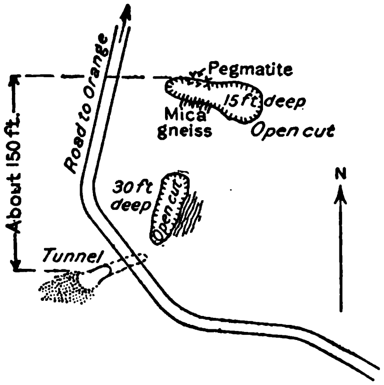

FIGURE 19.—Plan of workings at mica prospect half a mile southeast of Orange, Grafton County, N. H.

Ruggles mine.—The Ruggles mine is in Isinglass Mountain, 1¼ to 1½ miles northwest of Grafton Center (Cardigan railway station). Several sets of openings have been made, but only one set at the south end of the mountain was examined.

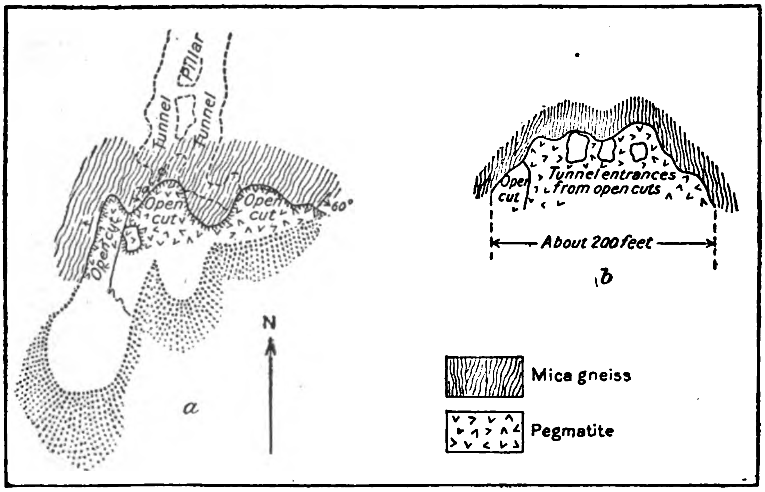

FIGURE 20.—Plan and cross section of part of Ruggles mica mine, near Grafton Center, Grafton County, N. H., showing workings and geology.

Other workings are reported to have been made below this on the mountain side half a mile farther north. The workings are on the steep south slope of the mountain and consist of three partly connected open cuts with tunnels driven back into the mountain from them. (See fig. 20.) These tunnels are large and irregular, opening into rooms and down stopes on the sides. Light was not available to examine them for more than 100 feet back, but they appear to be long and large. The open cut on the west is at a lower level than the other two cuts.

The country rock is mica gneiss in which biotite schist is prominent. Its banding is due to other layers, especially those rich in quartz. Near the pegmatite the gneiss is contorted and contains much tourmaline. The country rock strikes N. 10°–20° E., and dips from 60° E. to 70° W. The pegmatite is large and at the place opened forms a dome-shaped mass cutting across the gneiss, as shown in the cross section (fig. 20). On the sides the dip of the pegmatite is steep and is approximately conformable with the schistosity of the inclosing rock. The contact of the dome-shaped mass of pegmatite is irregular and pitches 20° S. in the workings on the surface. Back in the tunnel the pitch is more nearly horizontal. Horses of tourmalinated biotite schist are inclosed in the pegmatite. Evidently large masses of the pegmatite were found to be rich in mica, and in a few places good mica has been left in sight in pillars and some smaller mica that would pay to mine remains in the walls. The dumps are large and contain much mica, some that would yield sheets measuring from 3 by 4 inches down to punch size and scrap mica. During part of 1912 and 1913 the dumps around a few of the openings were worked over with good results. The mica from the Ruggles mine has a clear rum color and good cleavage, and is suitable for glazing and electric uses.

Kilton mine.—The M. M. Kilton mine is 1 mile N. 50° W. of Grafton Center (Cardigan railway station). It has been in operation in a small way for a number of years, and at the time of examination the prospects for opening a good deposit of mica were bright. The mine is in a steep hillside at the south end of Isinglass Mountain, about a third of a mile south of the south end of the Ruggles mine. The workings consist of an irregular open cut about 25 feet deep with rooms from its sides and a stripped area with surface excavations on the hill above. The relations are shown in the rough sketch in figure 21.

The country rock is mica gneiss composed of beds of schist containing variable quantities of biotite, muscovite, and quartz as principal constituents, with accessory minerals. The gneiss strikes east of north and has a nearly vertical dip. The pegmatite body is large and varies from coarse-grained rock in the deeper workings to fine pegmatitic granite carrying black tourmaline southwest of the mine. The excavations have developed a mass or roof of mica gneiss covering a part of the pegmatite on the east side of the mine. The lower contact between the pegmatite and the gneiss is approximately horizontal, with small rolls, but it is not conformable with the foliation of the gneiss. A small normal fault trending N. 10° E. and dipping 80° W., with a 3-foot downthrow to the west, cuts through the workings, as shown in the sketch. The mica occurs in streaks and pockets, and in the room at the north end of the open cut a large pocket or bunch of crystals was being removed at the time of examination. These crystals were 2 feet or less in diameter but were rather thin, some measuring only 2 or 3 inches. The quality of the sheet mica is good. Among the associated minerals of the pegmatite are black tourmaline, in crystals up to 4 inches in diameter, massive yellow beryl, and garnets.

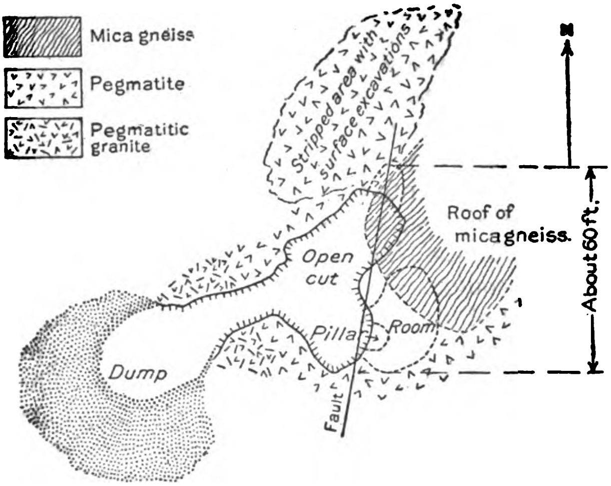

FIGURE 21.—Plan of Kilton mica mine, near Grafton Center, Grafton County, N. H., showing workings and geology.

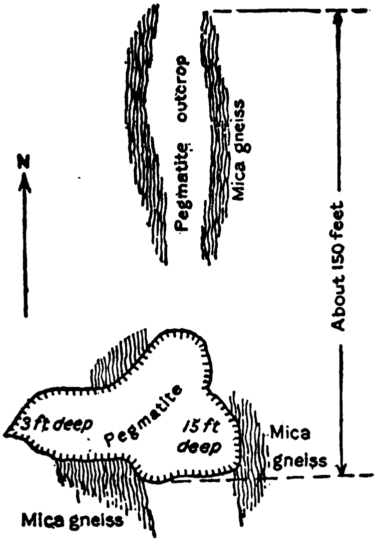

FIGURE 22.—Plan of De Mott mica mine, on Prescott Hill, Grafton County, N. H., showing workings and geology.

De Mott mine.—The De Mott mine is 2½ miles south of east of Grafton, near the crossroads on Prescott Hill. It has been worked by an irregular-shaped open cut 30 feet across and 3 to 15 feet deep. The country rock is highly foliated mica gneiss which strikes west of north and has a variable easterly dip. At the place where the work has been done the pegmatite cuts across the foliation of the gneiss, but north of the mine the pegmatite ledge is more nearly conformable with the inclosing gneiss, as seen in the prominent exposure extending up the hill. The relations between the country rock and pegmatite and the shape of the open cut are shown in the rough sketch in figure 22. The whole open cut is in pegmatite. Quartz occurs in irregular masses or segregations several feet thick in the pegmatite, and feldspar occurs in rough crystals 1 to 3 feet across. The mica is pockety or in bunches near the quartz. Beryl crystals, the largest 1 foot thick, are plentiful and a ton or more of them have been laid out near the dump. Only scrap mica was left around the mine.

United Mica Co.'s mine.—The mine of the United Mica Co. is on the southwest side of Prescott Hill, 2½ miles S. 50° W. of Grafton Center (Cardigan railway station). The company has a trimming house and plant with good equipment at Grafton Center. The mine has been worked by open cuts and tunnels with stopes driven northeastward into the hillside, as shown in figure 23. The main open cut is divided into upper and lower parts, the upper part being 15 to 20 feet higher than the lower. A large stope has been opened from it 200 feet to the northeast, with a few pillars left for the support of the roof. An inclined track extends from the open cut into the stope to a depth of about 30 feet in a distance of 100 feet, and the track is then run on a level 100 feet farther, to the end of the stope. From the head of the incline the track leads to the dump, a distance of about 150 feet. Another small cut was made above the main open cut to the north, and still another with a tunnel and stope to the southwest. The vein has been opened to a depth of about 60 feet from

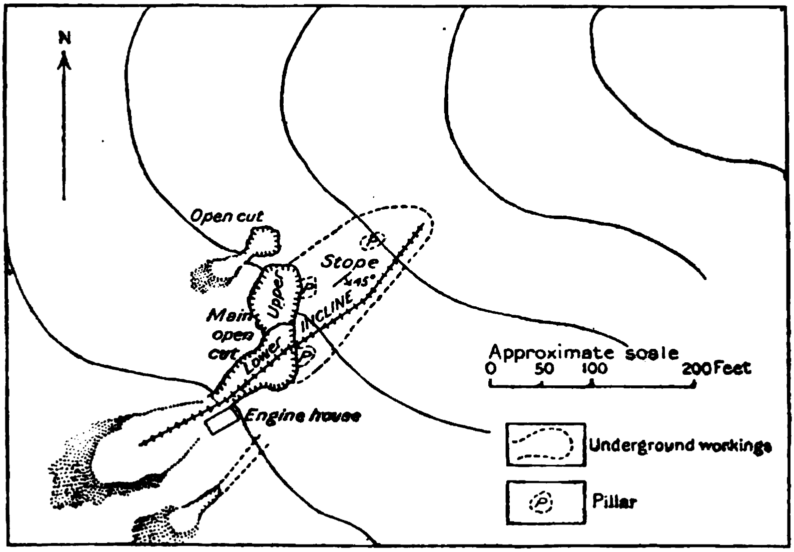

FIGURE 23.—Plan of United Mica Co.'s mine, on the southwest side of Prescott Hill, Grafton County, N. H. The stope is on a dip of 45° SE.

the outcrop in the highest cut, on an incline of about 45° SE. There are local variations in the incline where the vein rolled.

The pegmatite is variable in shape, pinching from a large, irregular mass 15 feet or more thick in the open cut to a vein 1 foot thick in the bottom of the incline below the track. The vein strikes about northeast and dips 45° SE. The pegmatite has branches or offshoots extending into the quartz-biotite gneiss country rock and also includes horses of the gneiss. In the lower part of the mine at the end of the stope the gneiss appears to roll, cutting the pegmatite off in a bulging mass. On the surface the pegmatite pinches out northeast of the workings. Further development would be required to learn whether the vein is thicker below the incline. The indications are that the ore body pitches southwest, down the hill, and in that case a part of it has been removed by erosion.

Quartz is plentiful in the pegmatite in large masses or segregations. One lens-shaped body 6 feet in greatest thickness and 30 feet long was encountered in the stopes. The feldspar is chiefly plagioclase, and much of it has been stained a dull green. The mica was scattered through the vein, but was richest near the quartz beds or lenses. In places the crystals were reported to be very plentiful. A little biotite mica is scattered through the pegmatite.

The mica has a clear rum color and is of good quality. Much of it was sold in the rough or after rough trimming, until the company erected its own manufacturing plant at Grafton Center, where washers, forms for electric apparatus, and ground mica were produced. To cover mining costs, machinery being supplied by the company, the factory allowed the mine $60 a ton for run of mine mica.

A quarter of a mile northeast of the mine a large pegmatite outcrop has been worked for feldspar. Boiler equipment, steam drills, etc., were installed for mining on a large scale. In places this pegmatite has large segregations of the constituent minerals, the feldspar crystals measuring 2 to 4 feet across, and irregular quartz masses several feet thick. Parts of the pegmatite contain black tourmaline and biotite mica as well as a little muscovite. Graphic granite intergrowths of feldspar and quartz are also present.

Reynolds beryl mine.—Mica of good quality with a clear rum color was found at the Reynolds beryl mine, on Sanders Hill, 2½ miles S. 25° W. of Grafton. This deposit is 400 feet higher than the valley on the north and has been worked for gem beryl. A quantity of mica was laid out during this work and would have helped defray the mining costs if it had been sold. The pegmatite crops out along the hillside and has been opened at two places. Massive translucent gray and smoky quartz, large crystals of potash feldspar, muscovite, biotite mica, black tourmaline, red garnets, green apatite, and green and golden beryl were the minerals observed on the dumps.

Wild Meadows mine.—The Wild Meadows mine is 2½ miles N. 75° E. of Grafton. It is not now in operation but has been worked by an open cut nearly 175 feet long and in places 20 feet deep, driven southwestward into a hillside, with a shaft, and two pits to the southwest, as shown in figure 24. The country rock is a rather coarse porphyritic biotite gneiss with interbedded mica schist striking N. 20°–40° E. and having a vertical dip. The pegmatite ranges from 8 to 12 feet in thickness and has a slightly sinuous course, approximately conformable with the inclosing gneiss. All the pegmatite was not removed during mining, masses of it being left in the sides of the open cut where it was folded or bulged out into the country rock. The texture of the pegmatite varies from medium to coarse grained, some of the feldspar crystals being 1 foot thick. Both potash feldspar and albite, or soda feldspar, are present. The mica left exposed in the walls of the cut was in small bunches of crystals. The mine yielded a clear light-colored mica with a fine cleavage. Crystals of black tourmaline, beryl, and red garnets are scattered through the pegmatite.

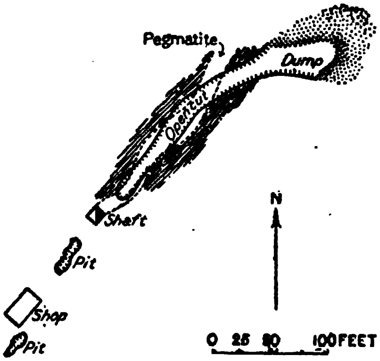

FIGURE 24.—Plan of Wild Meadows mica mine, 2¼ miles east-northeast of Grafton, Grafton County, N. H., showing workings and geology.

Mud mine.—The Mud mine is 2 miles S. 80° W. of Alexandria, in a steep hillside. It is now owned by the General Electric Co. but has not been operated for several years. It has been opened by a cut 150 feet long, 35 feet in greatest depth, and 30 feet wide and by a tunnel driven some 300 feet farther into the hill. Another open cut was made in the hillside at a higher level, and a shaft 70 feet deep sunk from it to the tunnel. The underground workings had caved badly and could not be examined, but some stoping is reported to have been done. The workings are shown in profile in figure 25. Down stopes 10 to 15 feet deep are reported to have been made in the floor of the tunnel, where good mica was found. The country rock is coarse porphyritic biotite gneiss. The pegmatite

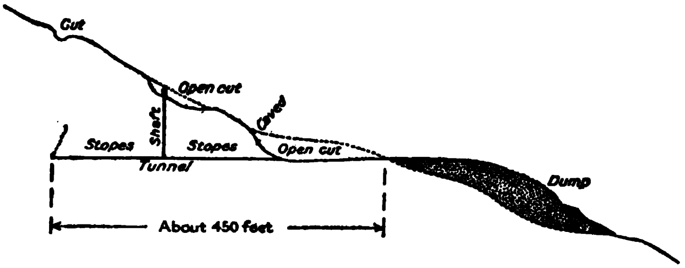

FIGURE 25.—Longitudinal section of workings at Mud mica mine, near Alexandria, Grafton County, N. H.

strikes about N. 35° E. and has a vertical dip. A prospect crosscut trench shows it to be at least 50 feet thick near the end of the open cut. Both plagioclase and potash feldspar are present in the pegmatite, and the mica apparently occurs in a streak 4 to 6 feet thick along the northwest wall. Some of the mica is partly specked.

Monarch mine.—The Monarch mine is 3 miles N. 40° W. of Alexandria, on Fowlers River. Two deposits were opened here but are not now in operation—one in low ground on the north side of the river and the other on the hillside about 200 yards to the south, across the river. The northern deposit was opened by a shaft inclined about 30° from the horizontal to a reported depth of 200 feet, with drifts and stopes on the vein to the northeast. Tracks and mine cars conveyed the waste to the dump, which spreads over a considerable area in a flat field northwest of the mine. The country rock is porphyritic biotite gneiss, with phases that resemble metamorphosed porphyritic granite. Plagioclase is the principal feldspar of the pegmatite. Biotite and a little red garnet were also seen.

The other deposit was worked by a pit or shaft 25 feet across and reported to be 20 feet deep on the lower side. The bank on the upper side is 18 feet higher than the water which fills the pit. The country rock is the same as at the northern workings. The pegmatite was not exposed at the time of examination. A few red garnets and pyrite crystals were seen on the dump. The small mica left around has a clear light rum color.

CHESHIRE COUNTY.

Brooks prospect.—A new mica prospect was opened in the spring of 1913 on the land of Charles Brooks, 1¾ miles west of East Sullivan.

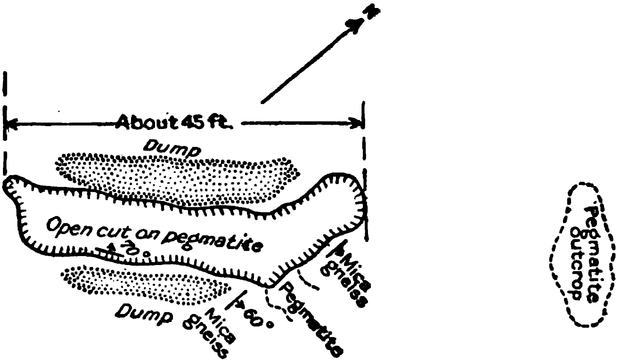

FIGURE 26.—Plan of Brooks mica prospect, near East Sullivan, Cheshire County, N. H.

The prospect lies in gently sloping ground and consists of an open cut 45 feet long, 8 to 10 feet wide, and 4 to 10 feet deep, of the shape shown in figure 26. The country rock is grayish muscovite-biotite gneiss striking north and dipping east. The pegmatite has a northeast strike in part of the open cut, but forks, one branch going north and the other (not developed) east. The contact of the pegmatite and gneiss on the southeast side of the cut dips 70° NW. More pegmatite crops out about 30 feet northeast of the open cut. Much of the pegmatite is only medium grained, but in places the texture is coarse. It is composed of a rather even mixture of potash feldspar, quartz, and mica (including a little biotite), with variable quantities of black tourmaline. The mica has been found in crystals measuring as much as 10 inches across. Some of the crystals show "wedge," "A," or "hair-lined" structure, and others split smoothly. The color is light rum. Sheets 3 by 4 inches could be cut from some of the rough crystals seen. Over 3 tons of rough run of mine mica is reported to have been taken from the open cut.

Price prospects.—Several prospects 1½ miles west of East Sullivan were opened in 1912 and 1913 by James W. Price. The principal one is along the edge of swampy ground where a large pegmatite outcrop stands some 15 to 18 feet above the ground. This mass strikes about north and is over 40 feet across. The working consists of an open cut 35 feet long and 4 feet deep on the west side of the pegmatite. Water causes much trouble in the work. The east wall of the pegmatite is mica gneiss. The texture of the pegmatite is very coarse in places, the quartz segregations being several feet across and the crystals of potash feldspar 1 or 2 feet thick. The mica is richest along the west side of the pegmatite in a streak about 4 feet thick. It has a clear light rum color and excellent cleavage. Six tons of run of mine mica is reported to have been removed from the cut, some of which would yield perfect sheets several inches across. Small beryl crystals were observed in and adjoining some of the quartz masses in the pegmatite.

About 250 yards to the south another open cut 20 feet long, 12 feet wide, and 8 feet deep had been made in a pegmatite outcrop. The pegmatite has a northerly trend. Crystals of potash feldspar over a foot thick were encountered in the pegmatite. The mica has a clear light rum color and is of good quality. About 2 tons of mica are reported to have been removed during mining, including one good crystal weighing 60 pounds.

About 200 yards farther south much mica has been found in a deposit of loose material consisting of fragments of pegmatite, feldspar, quartz, and earth. The mica is of good quality, and some fair-sized plates are reported to have been found. This deposit probably represents a bank of glacial drift consisting of material scooped out of a pegmatite mass not far distant. Two other possibilities exist—either that this loose material represents a pegmatite deposit decomposed in place, or that it is waste from older workings which have been covered over or filled up.

Nims mine.—A mica deposit on the land of E. S. Nims, half a mile north of Sullivan, was operated a few years ago by a mica company of Keene. Two open cuts were made, one 30 by 35 feet across and 14 feet deep and a smaller one a few feet to the north. A gasoline engine and air compressor with two air drills were used in quarrying. The country rock is porphyritic biotite gneiss which strikes north and has a variable easterly dip. The pegmatite cuts across the gneiss with a strike of N. 65° E. and dips 20° SE. along the southeast contact. The northwest contact is not exposed. A horse of mica gneiss is inclosed in the pegmatite a few feet northeast of the workings.

The texture of the pegmatite is very coarse, some of the crystals of potash feldspar measuring 4 feet across, all clean feldspar. Gray and smoky quartz occurs in irregular masses. The mica was scattered irregularly through the pegmatite, but in one place a streak or pocket of light-green "wedge," "A," and "fishbone" mica was encountered. About 5 tons of mica is reported to have been taken out, some of which would yield good sheets. Among the associated minerals in the pegmatite, observed chiefly on the dump, were triphylite, beryl, black tourmaline, and pyrite. The triphylite occurs in grayish masses several inches across, with blue streaks, due to alteration products, along the cleavage faces. The beryl crystals are opaque, are yellowish or greenish gray, and measure as much as 12 inches in diameter. Several hundred pounds could easily be gathered from the dumps.

Keene Mica Products Co.'s mine.—The mine of the Keene Mica Products Co. is 1 mile N. 40° W. of Gilsum. It has been worked by an irregular-shaped open cut 65 feet long and 15 to 25 feet wide, shown in plan view in figure 27. This cut is about 25 feet deep along the east side, where there is a slight overhanging wall, and 15 feet deep on the west side at the north end. The country rock is biotite gneiss carrying considerable tourmaline near the pegmatite. The gneiss strikes N. 15° W. and has a high but variable dip to the east. The pegmatite mass is large and irregular in shape. In part it is conformable with the foliation of the inclosing gneiss and in part it cuts the foliation. The relation between the gneiss and pegmatite exposed in the north end of the cut is shown in the cross section in figure 27. From the south side of the northern part of the open cut a trough-shaped horse of tourmaline-biotite gneiss, 12 to 15 feet thick, with pegmatite on each side of and below it, extends southward for more than 70 feet. Apparently this horse did not connect with the deeper roll of the gneiss on the north end of the cut shown in the cross section. The pitch of the pegmatite and gneiss contact along this side of the cut is about 15° N. This would mean that the surface relation restored would give the approximate contacts shown by the dotted lines in the plan, and such were the original conditions as reported by the miners.

The pegmatite is of diverse texture, some parts showing a very coarse crystallization with feldspar crystals 2 to 3 feet across and large quartz segregations. A little graphic granite was observed. The mica is richest near the hanging wall of the pegmatite, in streaks 3 to 7 feet thick. A thickness of 6 to 7 feet has been removed in mining, and in places the work has been extended to other parts of the pegmatite where pockets of mica were found. A mica streak, part of which has been worked, occurs along the west side of the horse of biotite gneiss. The face left on the pegmatite at this point shows a quantity of smaller sheet mica which will pay to remove. The mica obtained from this mine has a clear light rum color and is of good quality. A little biotite is associated with the muscovite.

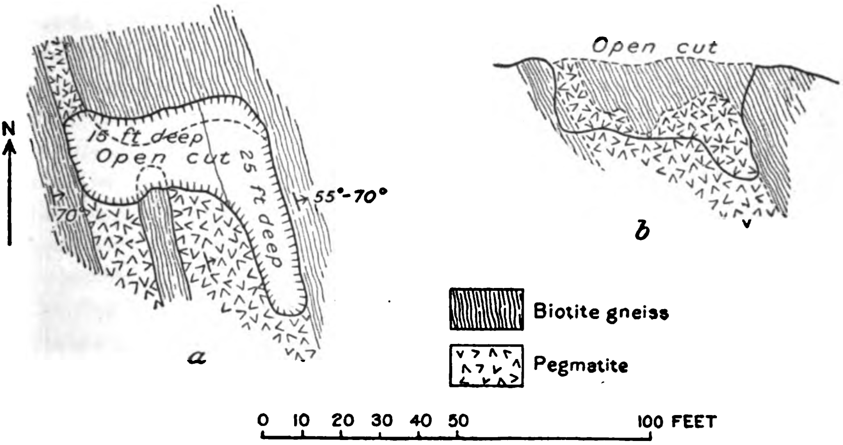

FIGURE 27.—Plan (a) and cross section (b) of Keene Mica Products Co.'s mine, 1 mile northwest of Gilsum, Cheshire County, N. H., showing geology.

The mine is equipped with a Sullivan gasoline-engine compressor, with two hand drills and one large drill. The mica is hauled to the company's plant at Keene, where numerous mica products are manufactured for the glazing and electric trades.

French mine.—The French mine of the American Insulator & Mica Co. is 1⅔ miles N. 25° W. of Gilsum, in the town of Alstead. It is an old mine, opened over 50 years ago and worked successively by the discoverer, a man named Mitchell, by a Mr. Bowers, and during the last 13 years by W. A. & C. H. French. The workings consist of a large open cut 60 yards long, 30 to 40 yards wide, and 20 to 60 feet deep, with smaller openings at the north end and a shaft or pit 20 feet deeper than the bottom of the cut, or 80 feet from the surface. Two steam drills are used in mining, and derrick hoists and an inclined track are used to remove waste and mica from the pit.

The country rock is mica gneiss with highly schistose layers. The gneiss strikes north to N. 30° E. and dips 60°–80° SE. The pegmatite occurs in a large irregular mass cutting the gneiss. Streaks or horses of gneiss and schist are inclosed in the pegmatite, retaining about the same strike and dip as the country rock. Two prominent horses of schist, extending nearly across the pit, were left standing above the level of the adjoining floor. The relations between the pegmatite and gneiss walls and horses are shown in figure 28. The area of the pegmatite is larger below ground than at the surface, so that the walls of the cut show pegmatite below with mica schist or gneiss above. Both the gneiss and pegmatite are somewhat altered by weathering, but in places the pegmatite is fresh and hard. The feldspar of the pegmatite is mostly the potash variety, with perthitic texture. Quartz does not occur in large segregations, and only a few small masses were observed. Black tourmaline is abundant in places and, near the bottom at the south end of the open cut, crystals 8 inches or less in diameter are associated with the mica. The mica is scattered irregularly through the pegmatite, there being some richer places, chiefly along the mica schist inclusions or walls. Mica crystals of

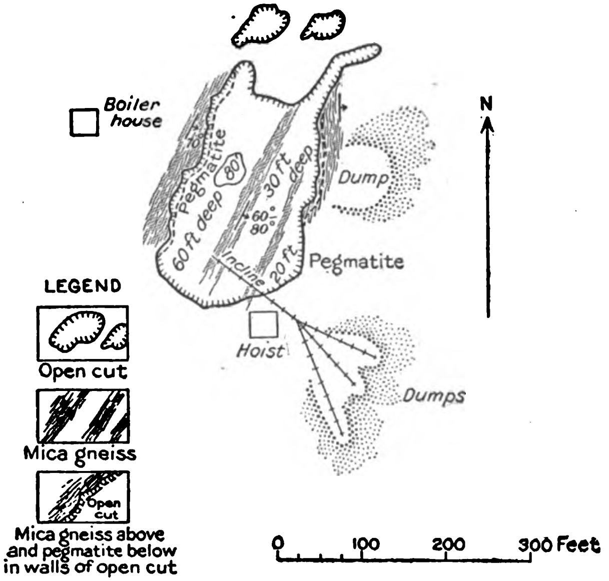

FIGURE 28.—Plan of French mica mine of American Insulator & Mica Co., 1¾ miles northwest of Gilsum, Cheshire County, N. H., showing workings and geology.

various sizes, some 18 inches or more in diameter, were abundant in the working face at the south end of the cut, below and south of the end of the incline. The mica has a good cleavage with very elastic sheets. Some of it is slightly smoked or dusted with minute particles between the laminæ.

Island mine.—The Island mica mine, 2 miles N. 20° W. of Gilsum, has not been operated for several years. The workings consisted of three open cuts and a short tunnel. Two of the open cuts were at the east foot of a small knoll (roches moutonnées) standing about 25 feet above the surrounding swampy ground. These open cuts were 20 and 25 feet deep, but are now filled with water. The third cut was made back into the knoll at a level a few feet above the lower cuts, but still 18 or 20 feet lower than the summit of the knoll. (See fig. 29.)

The country rock is biotite gneiss, which contains much black tourmaline near the pegmatite. The gneiss has a highly varied strike and dip adjoining the pegmatite, as shown by symbols in figure 29. It has been badly folded and crinkled in places by the intrusion of the pegmatite. The pegmatite is very irregular in shape, but has a generally westerly trend across the knoll. It incloses streaks of mica gneiss, and small stringers and bodies of it are intruded into the surrounding gneiss. Where the rock has been stripped bare by glacial action, north of the shop, a number of small curved lenses or bulblike masses of pegmatite are exposed in the crinkled gneiss. Along the contact of the main pegmatite these small masses appear to have been forced out into the gneiss, which has curved around them. A tongue or streak of mica gneiss included in the pegmatite extends in between the two lower cuts and may have connected with a body of gneiss exposed in the bottom of the upper open cut.

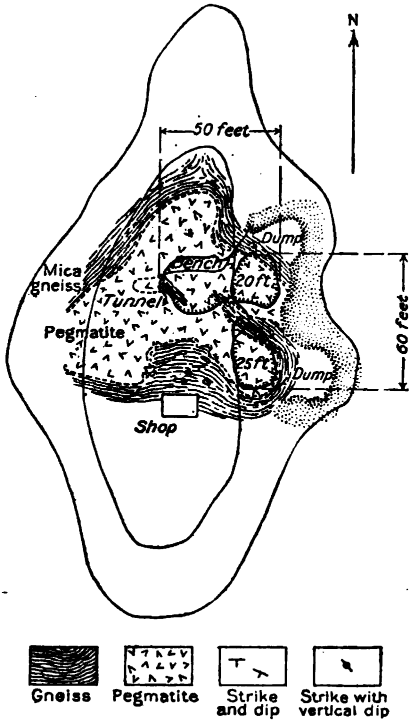

FIGURE 29.—Plan of Island mica mine, 2 miles N. 20° W. of Gilsum, Cheshire County, N. H., showing workings and geology.

The pegmatite contains large segregations of gray and smoky quartz, some graphic granite, pockets or bunches of mica (both muscovite and biotite), black tourmaline, green apatite, a few red garnets, and numerous beryl crystals. The mica seen was mostly "bunchy," but, of course, the best had been removed in the last mining. It has a clear rum color and is of good quality. A few biotite crystals are intergrown with the muscovite. The beryl crystals are as much as a foot in diameter and are varicolored—blue, blue-green, yellow-green, and rich and pale golden yellow. Good gem beryl has been found, but most of the beryl is translucent or opaque. Small golden beryl gems of exceptional beauty have been cut from clear portions of large crystals.

Tripp mine No. 1.—The Tripp mica mine No. 1 is about a quarter of a mile west of north of the Island mine, or 2¼ miles N. 20° W. of Gilsum. It has not been operated for several years, and at the time of visit the workings were filled with water and badly overgrown with brush. The workings consist of an open cut over 125 feet long in a north-south direction and 20 to 30 feet wide. The waste and ore were removed by an inclined track at the north end. Some of the pegmatite was coarse grained with large quartz segregations and crystals of potash feldspar over a foot thick. At the north end of the open cut a tree had been recently uprooted, exposing a deposit of mica several feet across in the pegmatite. Some of these mica crystals were 12 inches in diameter and sheets were seen that would cut 4 by 6 inches. The mica has a clear rum color and is of fair quality.

Davis Mica Co.'s mine.—The mine of the Davis Mica Co. is 2½ miles N. 15° W. of Gilsum, on the southwest side of the road leading to East Alstead. It has been worked by long open cuts on the outcrop and shafts with drifts and stopes. One shaft is reported to have been 125 feet deep. Good mine houses and shops were supplied and both aerial tram and track were used to facilitate mining. The workings are chiefly along the side of a low hill above swampy ground. From the mine houses the open cuts extend south about 100 yards and northeast about 100 yards to the road. (See fig. 30.) The mine was not in operation at the time of examination and many of the workings were filled with water.

The country rock is mica gneiss containing prominent layers of biotite schist with more or less tourmaline. The rocks have a variable north to northeast strike and a high east or southeast dip. The pegmatite is conformable with the inclosing gneiss through part of its course, and at the most productive part of the mine it forks, as shown by the outline of the workings in figure 30. A second pegmatite outcrops a few feet to the east of the mine and has been opened for mica near the road. The pegmatite of the main vein varies greatly in texture and composition. In the southern part of the workings biotite is extremely plentiful in the pegmatite, and some of it is intergrown with muscovite. In one part of the mine crushed biotite crystals from a quarter of an inch to 1 inch thick and as much as several inches across are so abundant as to make the pegmatite very dark gray. A little beryl, green apatite, and black tourmaline were also observed. The muscovite mica has a clear light rum color and is of good quality.

Tripp mine No. 2.—The Tripp mine No. 2 is a continuation, across the road to the northeast, of the Davis mine and has been opened by a series of open cuts along the outcrop. (See fig. 30.) The open cuts are more like stopes and are from 4 to 7 feet wide, according to the thickness of the vein. The depth could not be learned, as they were filled with water within 15 to 25 feet of the surface. The cuts or stopes showed a dip of 60° or more to the northwest, different from that of the southern part of the Davis mine. The small mica seen around the dumps indicates that a good grade was obtained.

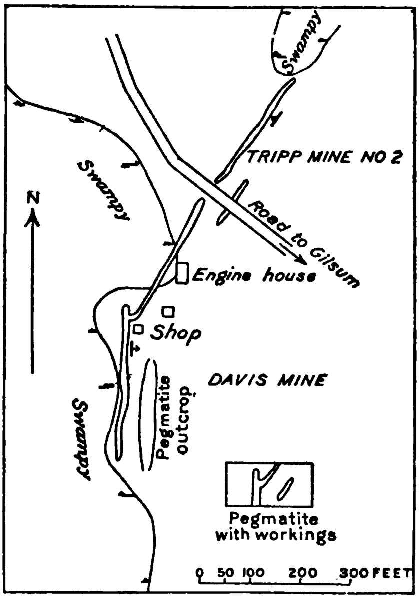

FIGURE 30.—Plan of workings at the Davis Mica Co.'s mine and Tripp mica mine No. 2, 2½ miles north-northwest of Gilsum, Cheshire County, N. H.

Parson mine.—The Parson mine, worked by the Fitzgibbon Mica Co., is 1¼ miles N. 5° E. of East Alstead, on the west side of the public road. The workings consist of several open cuts and pits within a distance of about 175 yards in a N. 30° E. direction, as shown in figure 31. These pits range from small size to 50 feet across and 200 feet long and from 10 to 40 feet deep. They were worked as open quarries, and derricks were used to remove waste and ore. The last work was done in 1906 or 1907 and was extensive.

The country rock is mica gneiss containing layers of highly foliated muscovite-biotite schist. The pegmatite is probably at least 100 feet thick but incloses streaks of schist. Large quartz segregations or veins are also inclosed in the pegmatite, and near these the mica is richest. Much black tourmaline, some in close association with the mica, was observed. The mica has a clear light rum color, and small pieces seen on the dumps possessed good cleavage. At the north end of the mine the pegmatite forks, part extending northeast along the west side of the road and part evidently crossing the road and forming the vein of the Granite State Mica Co.'s mine.

Granite State Mica Co.'s mine.—The mine of the Granite State Mica Co. was in operation during 1913. It was worked by an open cut 250 feet long in a northeast-southwest direction, as shown in figure 31. This cut is 35 feet deep in the southwest end, 45 feet deep in the middle, and 10 to 15 feet deep in the northeast end. An inclined track and a derrick have been used to remove waste and ore. At the time of examination the track had been abandoned and the derrick hoisted from a large pit below the position previously occupied by the track. A quantity of wall rock has been removed during mining.

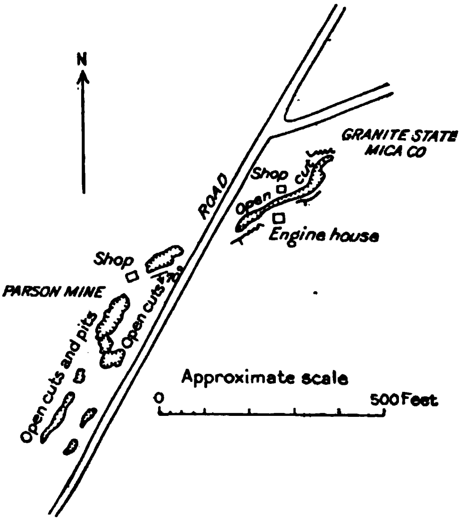

FIGURE 31.—Plan of the Parson mine and the mine of the Granite State Mica Co., 1½ miles north of East Alstead, Cheshire County, N. H.

The pegmatite cuts the mica gneiss country rock about conformably with its average attitude—that is, it trends northeast and has a high southeast dip. It was from 3 to 8 feet thick through much of the open cut and nearly 20 feet in the middle, though here it was thickest near the surface, pinching in depth. Much of the pegmatite is rather fine grained, but some has a coarse texture with large quartz segregations. The mica is most plentiful near the hanging wall, but some is scattered through the pegmatite or occurs along the footwall. Large crystals of mica, measuring over 2 feet across, are reported to have been found. The mica has a clear light rum color and is of good quality.

Lakin prospect.—A small mica prospect on the George A. Lakin place, 1½ miles N. 25° E. of East Alstead, was being tested during 1913 by E. Howard. Only a small amount of work had been done at the time of examination, consisting of a little digging and some blasting into an outcrop of pegmatite along a hillside. The pegmatite contains smoky-gray quartz segregations and in places grades into pegmatitic granite. Only small crystals of mica were seen, but 4 by 5 inch plates are reported to have been found. The better mica has a clear rum color, but part has been badly crushed.

VIRGINIA.

HENRY COUNTY.

Mica has been mined and prospected for at a number of localities near Ridgeway, in Henry County, Va. Attention was drawn to these mica deposits some years ago by Capt. McCray, now of Ridgeway. Capt. McCray opened many of the prospects and was instrumental in interesting persons from Pittsburgh, Pa., by whom most of the mining has been done.

Ridgeway is situated in a rather strongly dissected portion of the Piedmont Plateau. Some of the hills have moderate slopes, but in places the valleys have steep walls. The elevation at a United States Geological Survey bench mark near the Norfolk & Western Railway station is 834 feet above sea level. Some of the ridges in the vicinity, such as that on which the town of Ridgeway is situated, rise at least 100 feet higher.

The country rock in the Ridgeway region along the mica belt is chiefly diorite, more or less schistose, and in places cut by fine aplitic granite and pegmatite. Streaks of mica schist and garnet schist and a belt of soapstone were observed inclosed in the diorite country rock near the mica belt. The strike of the formations is in general northeast, with variations measured between N. 20° E. and N. 60° E. The dip of the bedding is generally high to the west or nearly vertical, but a few exceptions were noted.

Ridgeway Mica Co.'s mine.—The Ridgeway Mica Co., of Ridgeway, is an outgrowth of the former Pittsburgh Mica Co. The new company was formed by P. Lippert, of Pittsburgh, Pa., and associates after a period of idleness following rather extensive operations by the Pittsburgh Mica Co. The Ridgeway Mica Co. owns a large area of land around Ridgeway on which both mica and feldspar have been mined or prospected for. During 1913 the principal mine, about a quarter of a mile northwest of the railway station, was operated for mica, and prospecting was carried on at some of the other deposits.

The mine has been worked by open cuts, shafts, and stopes through a distance of about 160 feet horizontally in a N. 25° E. direction, and to a depth of about 120 feet, as shown in the generalized sections of figure 32. The workings are irregular in shape, corresponding to irregularities in the vein. Mining has been carried on from different openings, beginning with the cut at the north end and working successively southward and deeper to the present shaft and down stope from its bottom. Large stopes have been made, and these elbow out in places where there were bulges in the vein.

The country rock is schistose diorite which strikes about N. 25° E. and dips to the west at a high angle. There are local variations of dip and strike, especially around the irregularities of the pegmatite. In places the wall rock has been metamorphosed to quartz-biotite schist by contact with the pegmatite. The pegmatite as a whole is approximately conformable with the inclosing schistose diorite. It does not all lie between two plane parallel walls, but elbows out to the west by a series of bulges so that the average dip is about 75° W.

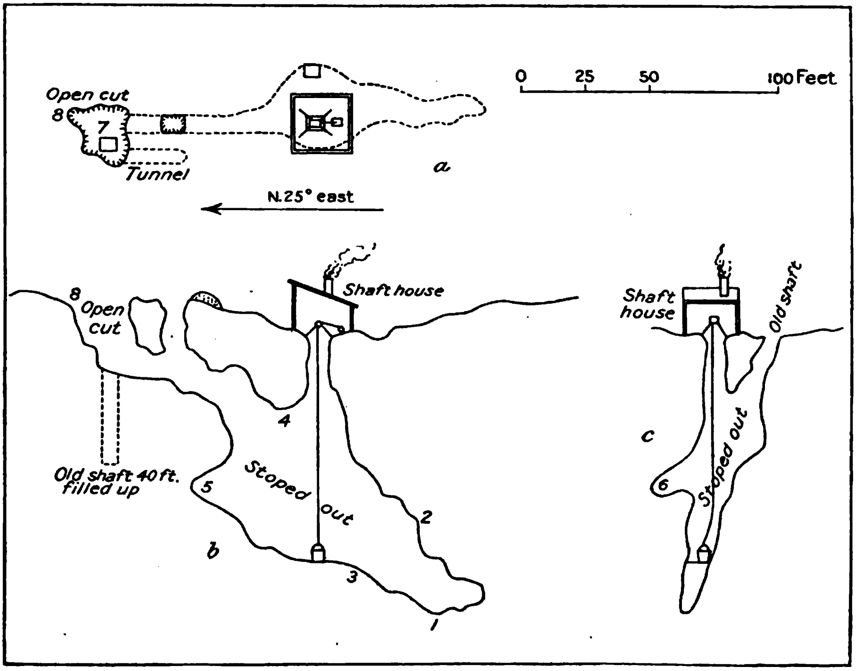

FIGURE 32.—Plan and sections of Ridgeway Mica Co.'s mine at Ridgeway, Henry County, Va. a, Plan; b, longitudinal section looking S. 65° E.; c, cross section looking N. 25° E.

Notes on the pegmatite at the different places numbered in figure 32 are given below:

1. Pegmatite 6 feet thick; contains fine mica, some in crystals weighing several hundred pounds.
2. Pegmatite 4 feet thick, becoming thicker above; contains good mica.
3. Pegmatite 1 foot thick.
4. Pegmatite 30 feet thick; yielded much mica.

5 and 6. Bulges in pegmatite. Schist roof over 5.

7. Pegmatite 30 feet thick, pinching to 4 feet at 8.

Mining has revealed a pay shoot of mica pitching about 35°–40° S. 25° W. in the body of the pegmatite. On the surface the pegmatite was traced about 250 feet S. 25° W. by prospect pits in which a little mica was found. Two pits 15 feet deep, about 400 feet south of the mine, opened mica-bearing pegmatite, but it is possible that these were not on the same vein.

The pegmatite consists of a fairly even mixture of feldspar, quartz, and mica. The feldspar is white albite and rarely occurs in crystals over a foot thick. The quartz is the light smoky-gray variety and occurs chiefly in irregular masses few of which are over 2 feet thick. Mica occurs in crystals ranging from those of small size to some over 2 feet in diameter. Large crystals are not rare, but many of them have the "A" structure strongly developed. A portion of a mica crystal measuring 18 by 20 inches and weighing about 42 pounds was recently presented to the United States National Museum by the Ridgeway Mica Co. This specimen has the "A" structure strongly developed on one side, but has a perfect cleavage over the full width of the crystal on the other side. Such a crystal would yield a quantity of good sheet mica between the "A" lines in those portions where the "A" structure occurs. There is necessarily a large percentage of scrap in "A" mica, but some good sheet mica can be cut between many of the "A" lines. Crystals that would yield plates 12 by 20 inches were obtained during the summer of 1913. The mica has a light smoky or brownish-green color and is classed as No. 1.

At the time of visit 10 men were employed at the mine, 5 below ground and 5 above, including two expert mica trimmers from Mitchell County, N. C. The equipment consists of a storage and trimming house, a boiler house, an engine and shaft house, a hoisting engine with bucket hoist, a steam drill, a mine car, etc. The Pittsburgh Mica Co. had a grinding mill near the site of the present trimming house, but this mill was burned down several years ago and the scrap mica is now shipped to mills in other places.

Another mica deposit was worked by the Pittsburgh Mica Co. about 250 feet S. 25° E. of the main mine. The workings were on a fairly large scale but are now rather inaccessible. The pegmatite body was large, at least 30 feet thick in one part, and was approximately conformable with the schistose diorite country rock. The feldspar of the pegmatite was considerably decomposed. The country rock was metamorphosed to biotite schist along the contact with the pegmatite. This mine is reported to have yielded a quantity of good mica.

Several other mica prospects and mines have been opened on either side of the road along the ridge to the northeast of the principal mine, on land belonging to the company. Most of these were discovered by Capt. McCray. The different deposits will be described in their order of location northeastward from the main mine.

Good mica was found in some pits a few hundred yards north of the mine on the west side of the ridge.

Across the road and about 100 yards north of east of the mine two test pits had been made for feldspar in a semidecomposed pegmatite. Fairly fresh potash feldspar had been found at a depth of several feet. About 600 yards northeast another prospect had been opened for feldspar on semidecomposed pegmatite.

Two-thirds of a mile northeast of the mine a pit had been opened on mica-bearing pegmatite near and on the southeast side of the road. Only small mica crystals had been left around the prospect, and the sheets had a greenish cast. About 200 yards north of this prospect, on the northwest side of the road, a shaft had been sunk 27 feet on a promising vein and good mica is reported to have been found. About 60 feet southwest a pegmatite mass, inclosing a 2-foot quartz vein, crops out in a plantation road. Mica in sheets as much as 4 inches across occurs in the decomposed feldspar along the southeast side of the quartz streak.

About 1 mile northeast of the main mine and 100 yards northwest of the road a trenchlike open cut 60 feet long in a N. 60° E. direction and a 25-foot shaft had been made on a mica-bearing pegmatite. This work was done by Capt. McCray a number of years ago and is said to have yielded about $1,500 worth of mica. The pegmatite body is 6 feet thick in the end of the cut and is inclosed in schistose diorite. The feldspar of this pegmatite is chiefly albite. About a quarter of a mile to the northeast, 150 yards northwest of the road, Capt. McCray sank another shaft about 30 feet deep on a promising mica deposit.

About a quarter of a mile southeast of the prospect last mentioned, or 1¼ miles northeast of the main mine, several shafts with short drifts had been made. These shafts were from 18 to 30 feet deep and cut decomposed pegmatite in schistose diorite. A quantity of small mica crystals with fine smooth cleavage were found. This mica is somewhat "specked" and may be classed part as No. 2 stove and part as good electric mica.

Capt. McCray has opened several other prospects in this region, in some of which he reports fairly promising mica veins.

The Ridgeway Mica Co. owns a feldspar quarry, from which several carloads of feldspar have been shipped, and other mica prospects on the same property about 2 miles south of Ridgeway.

Knight prospects.—Several mica prospects, none over 12 feet deep, have been opened on land now owned by H. A. Knight, 250 yards east of the railway station. These prospects are several years old, with the exception of one made within a year. They fall within an area about 150 feet long in a N. 25° E. direction and 100 feet wide. The country rock is diorite cut by aplite and inclosing several bodies of pegmatite. In the last prospect opened the pegmatite was 12 feet thick at the surface and 6 feet thick at a depth of 7 feet. The southeast wall of the pegmatite strikes N. 25° E. and has a vertical dip, and the northwest wall dips about 45° SE. Rough crystals of clear mica 6 or 8 inches across were found during prospecting.

HENRY AND PITTSYLVANIA COUNTIES.

Mica has been prospected and mined on a small scale at several places in the vicinity of Axton, Va., near the border of Henry and Pittsylvania counties. This region forms a part of the dissected Piedmont Plateau of Virginia and is similar in aspect to the Ridgeway country, already described. Elevations range from 700 feet above sea level in the valleys to over 900 feet on the ridges.

The country rock of the Axton region consists of mica and garnet schist and gneiss with included beds of hornblende schist, all cut by granite and pegmatite. The strikes of the schists and gneisses measured were chiefly between north and N. 30° E., but wide variations from these directions were noted. The dips are diverse.

Turner mine.—The C. S. Turner mine is on the summit of a hill about one-third of a mile N. 70° E. of Axton. It has been opened for a distance of about 100 yards in a N. 25° E. direction by several shafts and pits and a trench at the southwest end. One shaft is reported to have been 40 feet deep. The pits ranged from a few feet to 15 feet in depth. The country rock is decomposed mica schist cut by granite. The schist has an average strike of about N. 25° E. and a high dip to the east. The pegmatite occurs in overlapping lenslike masses approximately conformable with the inclosing schist. The mica is mostly clear and rather dark green in sheets over one-sixteenth of an inch thick. Some of it is a little specked. A quantity of "wedge" and "A" mica crystals are obtained along with the good mica. Mr. Turner states that about 10,000 pounds of mica was removed from the trench and yielded about 500 pounds of sheet mica and 9,500 pounds of scrap. The largest mica would have cut into sheets measuring 6 by 8 inches, but was sold for $2.50 a pound in the rough.

Harston mine.—The David W. Harston mine is about 3½ miles north of Axton, near the foot of a hill with a slope of about 15° WSW. The workings consist of a shaft about 20 feet deep, a tunnel extending 35 feet irregularly N. 60° E. from the shaft, and two small tunnels or gouges of about 6 feet each on the north and south sides of the shaft at about the same level as the main tunnel. A prospect pit had also been made about 30 feet north of the shaft. The position of the workings is shown in figure 33.

The country rock is mica schist cut by granite and pegmatite, partly decomposed to the depth of the workings. The schist near the mine strikes N. 60° E. and dips 35° SE. The pegmatite is very irregular in shape and the workings expose a mass about 15 feet thick in the bottom of the shaft with two branches forking out from it, one about parallel with the schistosity of the inclosing rock and the other cutting across it. These relations are shown in the cross section in figure 33. One arm of the pegmatite was opened by the prospect pit and the other was followed down by the shaft. Mica occurs in irregular-shaped bunches or pockets in the pegmatite, ranging from a few inches to over 3 feet across, but a few crystals are scattered through the mass of the rock. Mica was rather plentiful in the 2-foot streak of pegmatite exposed in the shaft. The largest yield came from the tunnel. Minerals associated with the mica are partly decomposed potash feldspar, gray smoky quartz, and a little black tourmaline. One crystal of beryl 2 inches in diameter was observed on the dump.

It is reported that about 11,000 pounds of mica was shipped from this mine, from which possibly 2,000 pounds of sheet mica could have been obtained. The largest crystal weighed several hundred pounds. The mica is brownish green and rather heavily "specked." Some of the crystals have been badly cracked and would yield only small plates, but others have a good smooth cleavage in large sheets.

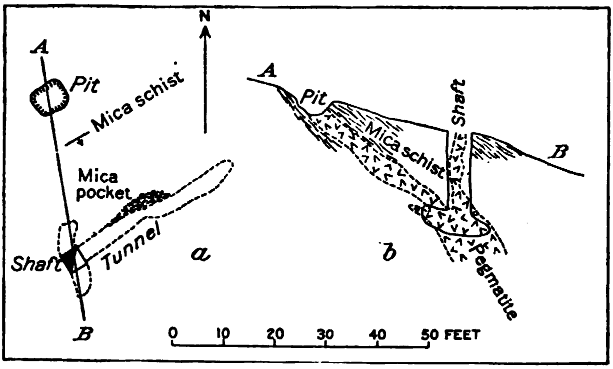

FIGURE 33.—Plan and section of Harston mica mine, 3½ miles north of Axton, Henry County, Va. *a*, Plan showing workings; *b*, cross section showing workings and geology.

About 250 feet S. 70° W. of the mine a mass of decomposed pegmatite 25 feet wide crops out in a road. Sheets of mica 3 inches in diameter were split from crystals found loose in the soil here. About 150 yards S. 80° W. a quantity of small sheet mica was plowed up in the light sandy soil of a cultivated field.

Willis mine.—A mica deposit has been prospected on the land of L. C. Willis, 3 miles north of Axton, by an 18-foot shaft, a short tunnel, and three pits in a northeast direction. The workings fall within an area 75 feet long and 20 feet wide. The country rock is mica and garnet schist. The pegmatite contains potash feldspar, which is partly decomposed, also a large streak of white quartz ranging from 2 feet thick in the shaft to about 6 feet thick a hundred feet to the southwest.

Only small mica was seen around the prospect, but larger and better material is said to have been carried away. Some of the small pieces examined have a good cleavage, but larger rough sheets several inches across were less perfect. The mica has a dark-green color in thick sheets and some is a little "specked." An interesting specimen of sharply folded or crumpled mica was found at this prospect.

Holland mine.—Mica was mined or prospected at two places on the land of D. S. Holland, 2 miles north of Axton. Only one of these was examined. This consisted of a small open cut with a shaft 20 feet deep filled with water. The country rock is schistose diorite and interbedded mica schist. The pegmatite is irregular in composition and grades into granitic pegmatite or coarse granite. Only small mica was seen at the mine, but about 2,000 pounds of better quality has been stored away. This mica is clear but rather dark green in thick sheets. Rectangular plates measuring 4 by 5 inches were seen at Mr. Holland's house.

FRANKLIN COUNTY.

Chestnut Mountain mines.—Mica has been mined and prospected at several places in the Chestnut Mountain region about 12 miles southeast of Rocky Mount, in Franklin County. The principal work was done by the Chestnut Mountain Mica Co., on the east side of the mountain, and consisted of an open cut 50 feet long and 5 to 12 feet deep along a steep hillside on the outcrop, with a shaft connecting with drifts and a crosscut tunnel about 20 feet lower at the foot of the hill, as shown in figure 34.

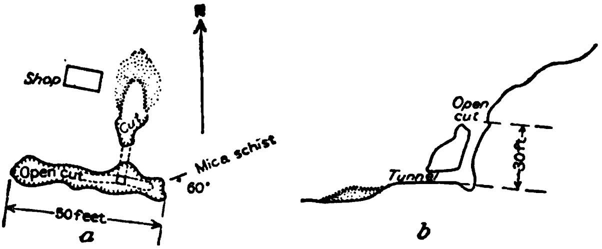

FIGURE 34.—Plan (*a*) and cross section (*b*) of Chestnut Mountain Mica Co.'s mine, on Chestnut Mountain, Franklin County, Va.

The country rock is mica and kyanite schist and gneiss. The strike of the inclosing schist as measured varied from N. 40° E. to N. 70° E. and the dip from 40° to 60° SE. The pegmatite cuts the country rock with a strike of N. 80° W. to nearly west and a variable dip of about 60° N. The pegmatite ranges from 2 feet in thickness in the east end of the cut to over 8 feet in the west end. The feldspar content has been strongly kaolinized and the inclosing schist has been badly decomposed. Mica seemed to be rather plentiful but was chiefly in small and "ruled" crystals, so that the yield of sheet mica would not be large. Under favorable conditions of transportation, it might pay to work the mine for scrap mica alone. A rotary screen had been set up to dry-clean the scrap mica from dirt and would not need much improvement to meet ordinary requirements. Several tons of scrap mica could be cleaned up from waste now lying around the mine.

A small open cut had been made about 200 feet west of the mine and about 50 feet higher up the hill. It may be on the same body of pegmatite as the lower working, but at this place the pegmatite contains more quartz with a quantity of "mica capping" or quartz mixed with small mica crystals.

About a quarter of a mile north of the mine a 15-foot shaft or pit had been sunk on a pegmatite near the main road to Rocky Mount. The pegmatite exposed in this opening was 10 feet thick. It was badly decomposed and the inclosed mica had been strongly broken and "ruled" into small sheets. A mica crystal 18 inches across was seen, but it was so badly crushed that only small sheets could be cut from it. Plates nearly 1 foot in diameter are reported to have been found. The mica is rather plentiful, but most of it is partly "specked." Large black tourmaline crystals were found in the pegmatite.

About 1½ miles northwest of the main mine there is an old prospect for mica consisting of a shaft about 20 feet deep. The country rock here is mica schist, which strikes N. 35° E. and dips 70° SE. The pegmatite is approximately conformable with the inclosing rock and is about 2½ feet thick near the surface. Hard blocks of mica capping 2 feet thick had been removed from the shaft. Only small mica crystals about 2 inches across were left on the dump. The pegmatite contains black tourmaline and opaque red garnets.

BEDFORD COUNTY.

American Asbestos Co.'s mine.—Mica was mined several years ago by the American Asbestos Co. on property now owned by Frank Mosher and associates 9 miles south of east of Bedford City, Bedford County. The deposit was worked by an open cut 40 feet long and 20 feet in greatest depth, with a shaft, now filled with water, reported to be 30 feet deep, in the end of the cut. The open cut was driven northwestward into a hillside about 30 feet above a creek. A hoist was arranged over the shaft, and a tram extends from it to the shop and storehouse about 40 feet to the northwest. The position of the workings, shop, etc., is shown in figure 35.

The country rock is hornblende schist or schistose diorite, badly weathered to a reddish-brown earth. The pegmatite is approximately conformable with the inclosing schist, striking N. 30° E. and having a nearly vertical dip. Where exposed in the open cut, it is nearly 20 feet thick. The east half is highly feldspathic and the west half contains more quartz and is richer in mica. The quartz occurs in irregular masses and in small sheets or lenses parallel with the walls of the pegmatite. A horse or sheet of hornblende schist 1 foot thick is also included in the pegmatite. Opaque reddish garnets are abundant, and some flattened garnet crystals are inclosed between the sheets of mica. Much of the mica has the "A" structure but would yield good sheets from the part between the "A" lines. Mica crystals 8 or 10 inches across were seen in the shop, where several tons of rough mica is stored.

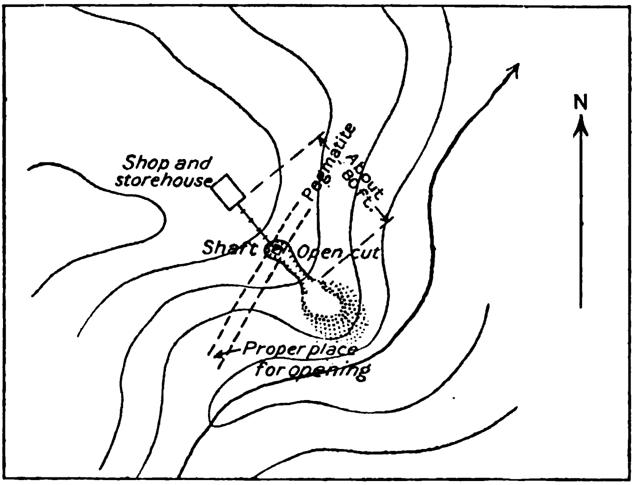

FIGURE 35.—Plan of the mica mine of the American Asbestos Co., 9 miles east-southeast of Bedford City, Bedford County, Va.

The mine could have been worked to better advantage from a lower level on the hillside about 75 feet to the southwest, as indicated in figure 35. A crosscut prospect trench would have located the pegmatite at this point, if continuous, as indicated in the figure, and mining could have been carried on by open work or drift with stopes to the northeast.

NORTH CAROLINA.

YADKIN COUNTY.

Hauser mine.—A new locality for mica in North Carolina was brought to the attention of the writer during 1913 by Mr. George H. Hauser, of Winston-Salem. It is in Yadkin County about 6 miles east of Yadkinville, and the propspects that have been opened are mostly on land owned by Mr. Hauser. An itinerant miner located the prospects several years ago and, after "groundhog" mining at a number of them, abandoned the work. The country is a roughly dissected part of the Piedmont Plateau and much of it is covered with timber. The country rock is diorite, in places strongly schistose.

The best deposit tested is about half a mile south of the main road leading west into Yadkinville. It was worked by numerous pits, trenches, and cuts and one shaft 40 feet deep within an area 250 yards long northwest to southeast and 200 feet wide, as shown in the rough sketch map (fig. 36). Outcrops of pegmatite carrying mica and another pit lie outside of this area. The exposures were not so good as to permit the working out of the relations between the pegmatite and the inclosing schistose diorite. In a pit across a branch on the northeast side of the mine the country rock is cut by a pegmatite body having a northeast strike and a vertical dip. The country rock strikes northwest with a vertical to high northeast dip. The position of the workings indicates either an irregular body of pegmatite with arms branching out, several veins, or a large blanket ledge (or ledges) with offshoots of smaller veins. The appearances suggest one or more beds of pegmatite cropping out on the hillside with a low dip to the northeast. If such prove to be the conditions, mining could be very effectively carried on by open cuts and drifts from this hillside.

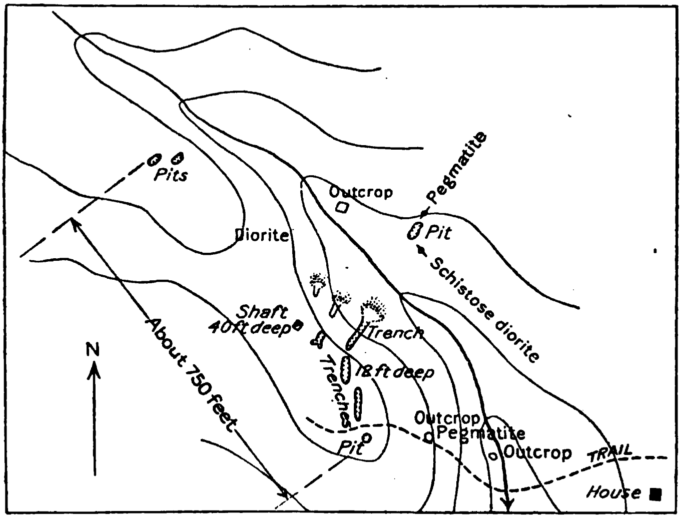

FIGURE 36.—Plan of Hauser mica mine, 6 miles east of Yadkinville, Yadkin County, N. C.

Large blocks of white, gray, and smoky quartz, some translucent and some nearly clear, were removed during mining. Some of this quartz shows imprints of numerous mica crystals. Semikaolinized feldspar was encountered in many of the workings, and an outcrop of pegmatite along the branch contains solid crystals of microcline 18 inches across, with small mica. In the principal workings mica seems to have been fairly plentiful. Only small crystals had been left around, but these were mostly of good quality, having a clear brownish-green color and very good cleavage. Some was slightly "specked." Some of the blocks have good crystal outline with fairly sharp faces, especially the crystals adjoining massive quartz. A few larger crystals of mica, measuring 4 to 6 inches across, found on the dumps, were badly crushed and had a very imperfect cleavage. Some of these included numerous small crystals of mica penetrating the laminæ at various angles. In the two pits at the northwest end of the workings much "A," "wedge," and "fishbone" mica was found. Masses of tangled blocks of this mica, measuring several inches across, had been left around the pits, but such material would be suitable only for grinding.

Another prospect was opened near a branch on the point of a low ridge a quarter of a mile southeast of this mine. A cut 6 feet deep and 20 feet long in a N. 70° W. direction was made on the north side of the ridge, exposing a pegmatite dike about 10 feet thick with a strike of N. 70° W. and a high dip to the south cutting schistose diorite. Most of the mica seen was in bunched masses of "wedge" and "A" crystals. Some slightly specked small sheet mica was also seen. The pegmatite contains feldspar crystals a foot thick, but most of the rock is very uneven grained.

Another mass of pegmatite crops out on the hillside about 100 feet to the north, across the branch. This pegmatite is coarse grained and from it crystals of mica 2 to 3 inches across have weathered out.

SOUTH CAROLINA.

LOCATION AND GENERAL GEOLOGY.

Earle Sloan[1] has described several mica deposits and mentioned the location of others in South Carolina. These deposits lie chiefly in the Piedmont Plateau in Oconee, Anderson, and Greenville counties. Some of them have been operated on a fairly large scale and yielded a quantity of good mica. A brief examination of those described below was made in October, 1913.

The rocks observed in the region around the mica mines consist largely of mica schist and gneiss with some kyanitic and garnetiferous phases, diorite, hornblende schist, and granite gneiss. The mica and garnet schists and gneisses are probably parts of the Carolina gneiss, as described by Keith in the geologic folios of western North Carolina. In this portion of the Piedmont Plateau weathering has been extensive, and in places the rocks are decomposed to depths of many feet.

GREENVILLE COUNTY.

Willimon mine.—One of the largest mica mines in South Carolina is that of R. C. Willimon, 9 miles southeast of Greenville. This mine has been operated intermittently for many years and has recently been leased by the J. E. Burleson Mica Co., of Sprucepine, N. C. Operations have been fairly extensive, but none of the underground workings were accessible at the time of examination. Openings have been made through a distance of 200 yards in a N. 60° E. direction, and a few prospect pits are not in the same line. The position of the numerous openings is shown in figure 37. According to reports, considerable drifting and stoping have been done and the deepest shaft is more than 100 feet deep. The rocks are soft, so that many of the workings have caved in, and it has been in the endeavor to find new ground and avoid old workings that so many shafts have been made. The following observations were made at the openings shown by numbers in figure 37:

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[1] Catalogue of the mineral localities of South Carolina: South Carolina Geol. Survey Bull. 2, 4th ser., pp. 142-149, 1908.

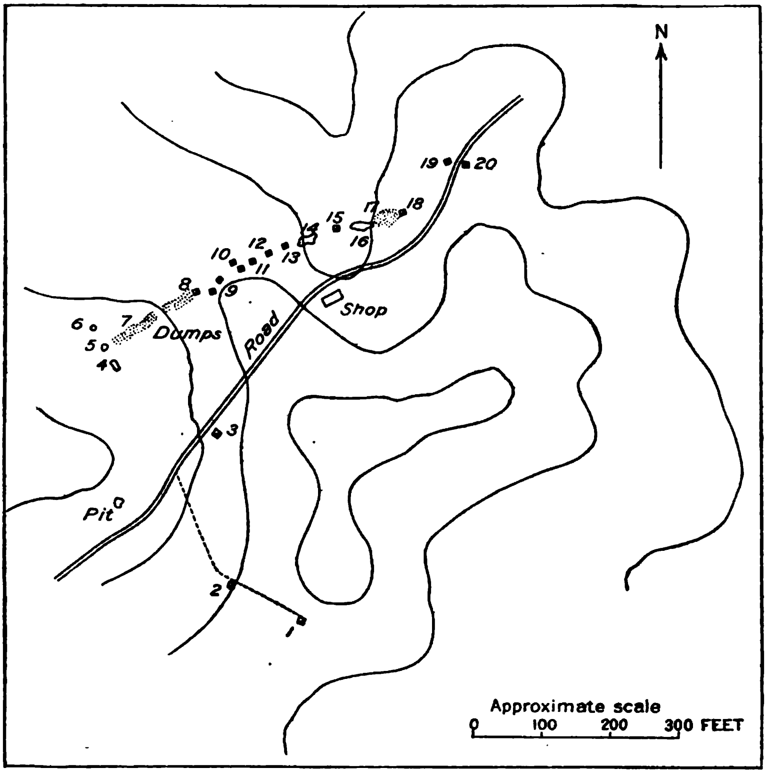

FIGURE 37.—Plan of workings at Willimon mica mine, 9 miles southeast of Greenville, Greenville County, S. C.

1. A shaft 25 feet deep in decomposed mica gneiss and pegmatite. The pegmatite is about 3 feet thick, strikes N. 60° E., and dips 75° NW. Mica in sheets 2 to 3 inches across.

2. Shaft 30 feet deep, partly caved in. Pegmatite 5 feet thick in decomposed kyanite-mica gneiss, both striking N. 60° E. and dipping 80° NW. Considerable small mica in dump.

3. Shaft 40 feet deep in decomposed mica and kyanite gneiss inclosing pegmatite.

4. Prospect trench; did not cut the vein.

5 and 6. Old shafts partly filled by caving. Only small mica left on the dumps.

7. Rather large dumps of waste removed from 8; contains some decomposed porphyritic granite.

8 and 9. Extensive underground workings, now mostly caved in. Pegmatite inclosed in decomposed mica gneiss.

10. Two new shafts, 10 and 30 feet deep, in mica gneiss on northwest side of the pegmatite.

11. Shaft more than 30 feet deep. Red clay near surface; decomposed pegmatite below. Small mica blocks of pegmatite and massive quartz on dump.

12. Old shaft in pegmatite.

13. New shaft 30 feet deep with water in bottom.

14. Old workings badly caved in. Much small mica on dumps.

15. Old shaft 20 feet or more deep, badly caved in. Small mica on dump.

16. Large pit or open cut on vein.

17. Large dumps of waste removed from 18.

18. Deep shaft, drifts, and stopes; badly caved in. Was equipped with steam. pump, hoist, etc. Much mica obtained from these workings.

19. Prospect pit; no pegmatite found in the decomposed mica gneiss.

20. Prospect pit in pegmatite. Small mica found.

General information gained by a study of the dumps and accessible openings and the surrounding country may be summarized thus: The country rock is composed of mica schist and gneiss, kyanitic in places, cut by porphyritic granite and pegmatite. All these rocks have been weathered to soft earth to a depth of at least 30 feet. Four pegmatite veins have been tested, one of which has proved large and continuous. This vein is over 10 feet thick in places and contains segregations or masses of quartz. The pegmatite veins are approximately conformable with the inclosing rock, striking about N. 60°–65° E. and having vertical to high northwest dips.

Little could be learned of the quantity of mica the mine has produced or of the size of the better sheets. Possibly 25 tons of small sheet and scrap mica was lying around the workings. This mica could be screened and used for grinding. The small sheet mica seen had a clear amber to rum color and good cleavage. Some of it was considerably "ruled."

ANDERSON COUNTY.

Gailliard mine.—A deposit of mica has been worked extensively on the Warren Gailliard place (formerly J. J. Fretwell place) about 6 miles S. 75° W. of Starr. The mine has been worked at two different periods, but was idle at the time of examination. The principal workings fall within a distance of about 900 feet in a N. 20° E. direction, as shown in figure 38. Eight shafts, ranging from 15 to 40 feet in depth, and several pits have been made. Drifts were run from the shafts and stopes made wherever rich vein material was found. Many of the workings have caved in and could not be examined.

The country rock as exposed in the branch south of the mine is strongly folded biotite gneiss injected with granite and pegmatite. The strike and dip are variable, the strike averaging northeast and the dip southeast. The gneiss and included pegmatite exposed in the workings are both deeply weathered. Masses of white quartz were encountered in the three main groups of workings. In the middle group the quartz is still exposed as an irregular vein 2 to 3 feet thick inclosed in the decomposed pegmatite and lying about 3 feet from the west wall of the vein: In places the quartz is gray, and some of it is smoky. The pegmatite varies in thickness, being at least 18 feet thick in the middle workings and probably ranging from about 8 to 25 feet, including streaks or horses of mica gneiss. Whether the three main groups of shafts and the tunnel to the south are all on the same pegmatite body could not be determined. From the nature of the work done it is evident that the mica is pockety and irregularly scattered through the pegmatite. It is most plentiful in decomposed feldspar next to quartz veins and masses. Some is partly intergrown with quartz. Most of the mica seen was small, occurring either in small crystals or in larger crystals cut by ruling into ribbons and small plates. Crystals yielding sheets 10 inches square are reported to have been obtained when mining was in progress. The mica is clear and of good quality, splitting well.

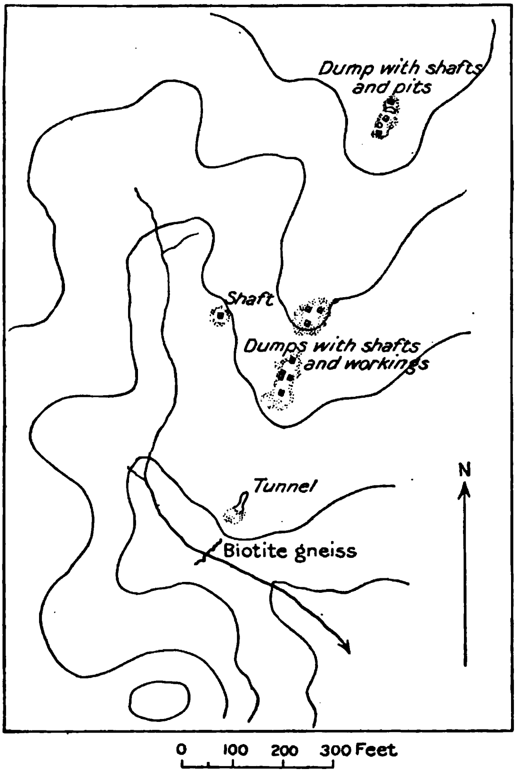

FIGURE 38.—Plan of workings at Gailliard mica mine, 6 miles S. 75° W. of Starr, Anderson County, S. C. Approximate contour interval 15 feet.

Several tons of scrap mica could be obtained by screening and washing the waste mixed with kaolin on the dumps, and if such material had been saved during the first operations it would have gone far toward defraying the cost of mining.

A shaft had been sunk about 150 feet west of the main line of workings. A body of pegmatite similar in composition to that in the main workings was encountered and a quantity of small mica had been removed.

Fretwell prospects.—A small amount of prospecting has been done on the old Hall place, now owned by J. J. Fretwell, about 1½ miles west of Barnes, where a mica belt has been traced for nearly a mile in a northeasterly direction. Three deposits cropping out on small knolls about 200 yards apart were examined. The pegmatite crops out as white gravelly quartz soil, with blocks of white quartz and mica plates scattered through it. This soil can be traced rather plainly over the fields because it contrasts with the darker earth and red clay soil formed by the decomposition of the inclosing schists. Each outcrop has a trend of about N. 60° E., as shown in figure 39. It is probable that they are separate bodies of pegmatite and do not represent one continuous mass. The country rock is mica gneiss composed of many schist layers. Both the mica gneiss and the pegmatite have been deeply weathered.

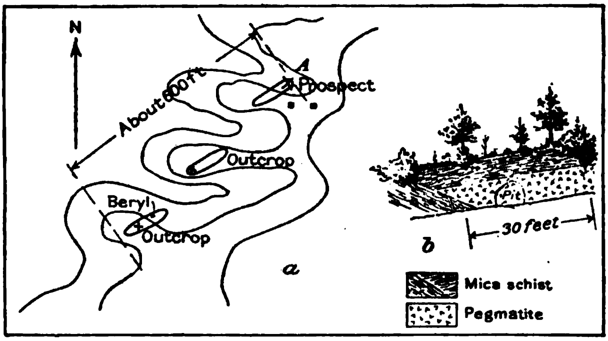

FIGURE 39.—Outcrops at Fretwell mica prospect, 1½ miles west of Barnes, Anderson County, S. C. *a*, Sketch plan; *b*, cross section at prospect marked *A*.

Practically no work has been done on the middle and southwest pegmatite masses, but weathered sheets of mica are abundant at the prospects marked "X" in figure 39. An opaque yellowish beryl crystal was found at the place indicated in the sketch map. At the northeast end of the area examined two prospect pits had been opened on each side of a small gully. Nothing could be seen of the pegmatite in the pit on the south side, but the later work on the north side, at the place marked "A" in figure 39, yielded promising mica. A cross section of the formations encountered at this place is shown in the figure. The pegmatite appears to be a nearly horizontal bed inclosed in mica schist, but it may have an easterly strike and a northerly dip. The mica schist on the west wall strikes east of north and dips about 25° E. Fifty feet west of the prospect the schist strikes N. 40° E. and dips 35° SE. Massive white quartz bowlders crop out east of the prospect. The mica occurs in pockets or bunches of crystals and irregularly scattered through the pegmatite. Crystals of mica as much as 8 inches across have been found, and specimens were seen which would cut to 2 by 3 inches. The mica obtained near the surface is rather badly clay stained, but the better pieces are of a clear light rum color and have a good cleavage.

The pegmatite is decomposed and soft and can be easily excavated. The deposit should be prospected by a face cut back into the north side of the gully, extending east as far as mica is found, and further work should be carried on at the best showings of mica.

Another mica prospect has been opened on land owned by Mr. Fretwell, on the northeast bank of Savannah River about a quarter of a mile above the mouth of Big Generostee River. This prospect is about a mile south of the Gailliard mine, or 7 miles S. 65° W. of Starr. An open cut was made some years ago around a quartz outcrop on the hillside, revealing pegmatite with mica crystals of promising size and crystals of potash feldspar 18 inches across. Bluish-green and yellowish beryl crystals were found, one of which was over 4 inches in diameter. A 30-foot tunnel was driven in under the the open cut, but without encouraging results. The country rock is fine biotite gneiss cut irregularly by the pegmatite.

Wharton mine.—Mica was mined on the Sam Wharton place, 6½ miles N. 82° W. of Iva, several years ago. The workings consisted of an open cut 40 feet long in a N. 60° E. direction along the northwest side of a small branch, with two crosscuts from the hillside, and a crosscut tunnel with a room at the end a few feet northeast of the open cut. The country rock is decomposed mica schist inclosing streaks of hornblende schist striking northeast and having a variable dip. The pegmatite cuts the country rock irregularly and pinches from a thickness of 15 feet in the open cut down to a few inches in the tunnel at the northeast end of the workings. The formations are weathered and easily excavated. Rough sheets of mica 8 inches across were seen on the dump, with a few pieces that would cut 2 by 3 inch plates. This mica has greenish cast and splits well.

Another prospect pit was made 200 feet west-southwest of the main workings. Blocks of hard pegmatite containing small mica were left on the dump, but little could be seen of the formation.

Sherard mine.—Mining has been carried on intermittently on the old Vandiver Sherard place, 6½ miles N. 80° W. of Iva, about a quarter of a mile southwest of the Sam Wharton mine on the same belt of mica deposits. The first working was a 30-foot shaft with drifts. Later a 25-foot shaft was sunk about 100 feet N. 20° E. of the first shaft, and drifts were run out to the north and south. A crosscut tunnel 140 feet long was next driven in from the hillside below on the east, and the mine was worked through it. At about halfway in this tunnel cut another vein, on which drifts were run. After this crosscut tunnel caved in, a new shaft was sunk west of the vein to a depth of 35 feet, and a crosscut was made to the vein. These workings are very irregular and include some unnecessary work. Their position is shown in figure 40.

The country rock is diorite or hornblende gneiss, with streaks of mica schist. The pegmatites cut the inclosing rocks irregularly. The main vein is as much as 15 feet thick and has a N. 20° E. strike and a west dip. It contains quartz segregations, two veins of which are exposed in the first shaft made. The pegmatite cut in the crosscut tunnel is about 10 feet thick, and includes horses or streaks of mica schist. Only small mica was found in this vein. The mica obtained from the main vein has a slightly smoky color and part is "specked." It has a good cleavage, and some of the small crystals seen were clean and sound. Good-sized sheets are reported to have been obtained during mining.

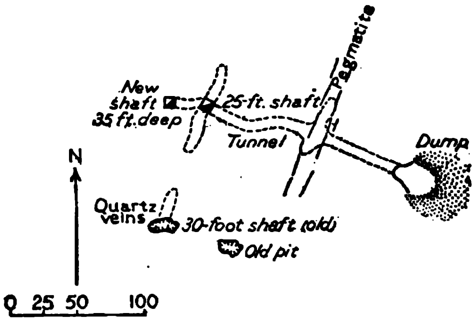

FIGURE 40.—Plan of workings at Sherard mica mine, 6½ miles N. 80° W. of Iva, Anderson County, S. C.

Terry prospect.—A mica prospect was opened on the old Terry place, about 6 miles west of Iva, by an open cut 35 feet long in the side of a knoll, but at present little can be seen of the formations. Massive white quartz is abundant on the summit of the knoll and much very small mica has been left around the pit.

McConnell prospect.—A prospect opened on the place of J. N. S. McConnell, 3½ miles north of Anderson, yielded promising specimens of mica with beryl crystals of good color, reported to be nearly emeralds. When examined the workings consisted of a trench 45 feet long in a N. 70° E. direction, 15 feet wide, and 5 feet deep, and a crosscut trench entering at the west end. The country rock is weathered to a dark reddish-brown sandy soil, and no outcrops were seen near the prospect. The soil has probably been formed by the weathering of a biotite or hornblende granite and carries small blocks of diorite. The pegmatite is not now exposed, but the dump contains kaolinized feldspar, blocks of massive white quartz, smoky and colorless quartz in rough crystals, weathered plates of mica 8 inches or less across, large dark-red garnets, black tourmaline, limonite pseudomorphs after pyrite, and black stains of manganese oxide. The mica remaining after the weathered parts are trimmed off is clear and of good quality. The principal workings are along the summit of a ridge extending west of north down to Little River. The deposits have been tested by pits for a distance of 75 yards in a S. 15° E. direction up the ridge. The deepest pit was probably not more than 15 feet deep, and most of the openings are partly filled. The country rock is mica gneiss, but its relations to the pegmatite were not visible. The pegmatite is at least 20 feet thick, as shown by the position of the prospect pits. Massive ledges or veins of white quartz form part of the pegmatite. Only small mica sheets were seen around the mine, but large crystals are reported to have been found. The mica is of a clear light rum color and of good quality.

Welborn prospect.—A prospect reported to be about 10 feet deep was opened on the land of W. C. Welborn, about 6 miles east-southeast of Pendleton, a number of years ago, but this has now been filled up. The country rock at this place is mica gneiss which has been badly weathered. The gneiss strikes N. 60° E. and dips 55° SE., and small beds of pegmatite exposed in the roadside cut the bedding nearly perpendicularly. Blocks of white quartz were left on the surface. So much scrap mica is mixed through the soil around the prospect as to indicate that the deposit is rich. It may have been abandoned because the mica is rather heavily "specked," as at one time that variety was not in strong demand. Some of the mica has the "A" structure but would yield good sheets from the portion between the "A" markings. A few rough sheets 8 inches in diameter were seen.

OCONEE COUNTY.

Leroy prospects.—Several deposits of mica have been prospected on the G. W. Leroy place, 5 miles northeast of Seneca. The mining or prospecting here was done by Thaddeus Leroy, who owns other mica prospects on land adjoining on the west. Some of the smaller prospects were tested by a few days' work, and the mica obtained is said to have paid wages of over $3 a day for the work.

Other prospects for mica have been tested or are known on the places of John Dyer and J. F. Smith, one-half and three-fourths of a mile south of Leroy's.

TEXAS.

CULBERSON COUNTY.

Texas Mica Co.'s mine.—Outcrops of mica were discovered in the Van Horn Mountains, in Culberson County (formerly El Paso County), Tex., some 20 years ago by Ben Kraus, of Pecos. The deposits lay idle until 1910, when they were located by the Texas Mica Co., of

Pecos, and the inclosing two sections of land were purchased from the State. The prospects lie on the west side of the Van Horn Mountains about 15 miles S. 20° W. of Van Horn. Van Horn is on the Texas & Pacific Railway, but the nearest railroad station is Dalberg, on the Southern Pacific line, about 9 miles northwest of the mine. The dirt road to Van Horn crosses the railroad about 6 miles north of the mine.

The mining developments are not extensive and consist of two open cuts on the principal deposit and several smaller prospects at other places. Trails and roads have been built from the camp to some of the prospects. A small grinding mill was erected for experimental work with some of the products mined. The mill is operated by an 18-horsepower gasoline engine, which also furnishes power for an air compressor and drill. The company has been interested in the development of two products, mica and micaceous rock, suitable for giving a "micolithic" finish to cement and other structures.

The Van Horn Mountains consist of a main range over 15 miles long with a north-south scarp on the east, broken plateaus and ridges in the middle, and a less prominent range on the west. This smaller western range trends west of north, diverging from the main mass of the mountains, and sinks into the surrounding basin or plains a few miles north of the mica deposits. These deposits occur in the rough hills formed by valleys and eroded surfaces of the west range of the mountains. The most of the hill slopes are steep, in places breaking into rocky cliffs. Elevations near the deposits range from about 4,200 feet above sea level at the camp to over 5,000 feet at the north end of the property. The Van Horn Mountains attain greater elevations (5,622 feet) in the Van Horn Peaks, 2 miles east of the mica prospects, and along the crest of the eastern range, 5 miles east of the prospects.

The region is a typical desert and has the characteristic desert vegetation, composed of sagebrush, various species of cactus, etc. Water for general camp use is caught during rains in a natural cistern or reservoir in a draw about 200 yards east of the camp. Drinking water is hauled from a well about 1½ miles west of the camp.

The mica deposits occur in an area of pre-Cambrian crystalline rocks exposed by the erosion of overlying sedimentary formations. The adjacent sedimentary rock is chiefly rather heavy bedded gray limestone, cherty in places, with a little limy shale, and probably is of Carboniferous (Pennsylvanian) age. An area of such rock in about the proper position for correlation, in the south end of the Carrizo Mountains, 8 miles north of the mica prospects, has been mapped as the Hueco formation by G. B. Richardson.[1]

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[1] Notes on northern border of the Chispa quadrangle, made during areal mapping of the Van Horn quadrangle.

The crystalline rocks consist of quartz-mica gneisses and schists, biotite schist, hornblende schist, and pegmatite. The quartz-mica gneisses and schists are composed chiefly of quartz, muscovite, and biotite, with variable quantities of feldspar. They are from fine to medium grained and are light to dark gray according to the proportion of biotite they contain. Some of the outcrops are red and reddish brown from the abundance of iron oxides present. The biotite schist is a black, strongly laminated rock composed of coarse lustrous scales of biotite mica with small quantities of quartz and feldspar. The hornblende schist is a medium-grained greenish-black foliated rock in which hornblende is a prominent constituent. In one place it is highly garnetiferous, containing garnet crystals as much as half an inch in diameter. The pegmatite is prevailingly reddish and exhibits many of the irregularities of texture common to that rock. In most of the outcrops it is composed chiefly of feldspar and quartz with small quantities of mica. Locally mica is abundant. Most of the feldspar is reddish orthoclase or microcline. It occurs as small grains mixed with quartz, with or without mica, in typical granite texture, as graphic granite, and in some places in crystals measuring over 2 feet in thickness. The quartz occurs also in irregular gray to white masses or segregations ranging from 1 inch to 5 feet thick. These masses of quartz are apparently scattered at random through the pegmatite. Most of the mica in the pegmatite is muscovite. It ranges from small scales to crystals 1 foot across. The mica crystals occupy no regular position in the rock and vary greatly in abundance in different bodies of pegmatite and in different parts of the same body.

The crystalline rocks outcrop in an irregular-shaped area about 2 miles long from north to south and a little over half a mile wide. They have been complexly folded, as shown by the dip and strike marks in figure 41. These pre-Cambrian gneisses and schists have been cut by pegmatite both parallel to and across their schistosity. The pegmatite, however, does not cut the surrounding limestones, which overlie the crystalline rocks unconformably and dip away from the area on all sides at varying angles. The structure is that of an elongated dome from which the overlying sedimentary beds have been eroded, exposing the core of underlying crystalline rocks.

The mica of value as sheet mica and for grinding into pure products is found in pegmatite, which is abundant in the area of crystalline rocks and occurs in ledges and streaks ranging from a few inches to over 100 feet thick. Sheet mica of promise has been found in only a few of these deposits. The principal working is on the east side of a draw about 150 yards from the camp. It consists of two open cuts in a steep hillside. The larger cut is about 65 feet long in a north-south direction and 5 to 20 feet deep. The other opening lies a few feet to the northwest and is a crosscut trench about 35 feet long with a depth of 15 feet at the inner end. These workings are on a large pegmatite dike with a northerly strike. The west wall of the pegmatite is not exposed, but on the east there is a rather fine grained red gneiss composed of quartz, feldspar, biotite, and muscovite. The pegmatite incloses horses or streaks of both hornblende and quartz-mica schists parallel with its own strike.

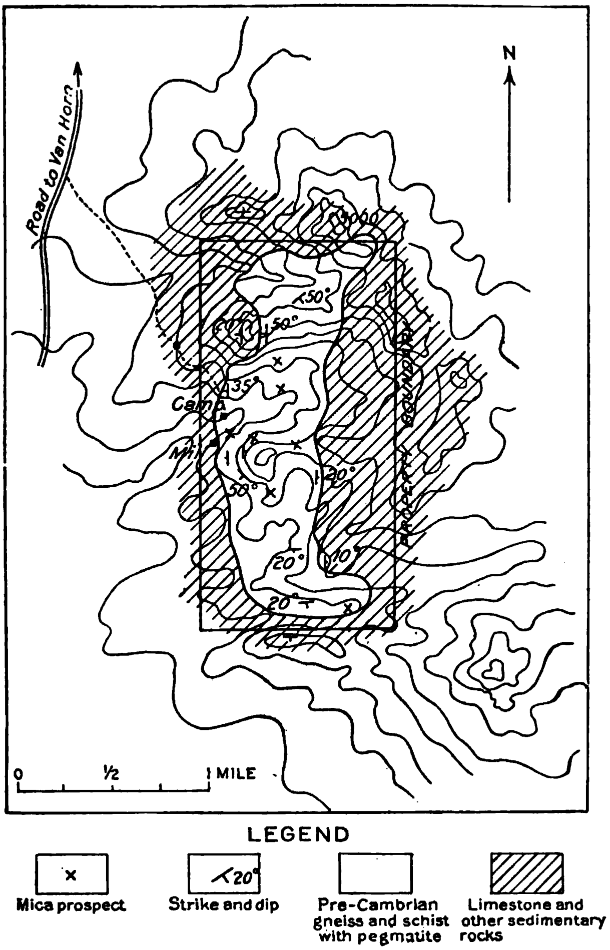

FIGURE 41.—Sketch of Texas Mica Co.'s holdings, 15 miles southwest of Van Horn, Culberson County, Tex., showing topography and geology.

The mica was found richest in an irregular streak developed by the largest open cut. Several crystals are commonly found near together, and these bunches are scattered through nearly barren pegmatite at intervals of a few feet. From 4 to 5 tons of mica were taken from this cut. Much of the mica is small, but some was seen in the storage house that would trim into sheets 4 by 6 inches. The better crystals are firm and split fairly well. Most of the sheet mica so far mined would be punched into washers and cut into small sheets. The mica has a greenish-brown color in sheets one-sixteenth of an inch thick. Most of it is slightly specked and some is rather strongly specked with magnetite. Some of the larger mica crystals seen had been badly crushed and "ruled." Others were wedge shaped or showed "A" markings.

In two of the other prospects good sound mica, but in small crystals only, was observed. Only a small amount of work had been done on these prospects, and their possibilities had not been determined.

At several places on the property the crystalline rocks have a composition which makes them useful, when ground and properly mixed with other ingredients, in giving a natural-rock finish ("micolithic" finish) to cement and other construction material. The special rock used in the different mixtures varies with the effect desired. Several phases of the quartz-biotite-muscovite schist and gneiss have been ground for this purpose. A large body of coarse biotite schist supplies an abundance of black mica with which to vary the tone of the "micolithic" finish. This biotite schist occurs as a bed in contact with pegmatite. Several feet from the contact it is even-grained, finely laminated schist composed largely of biotite in plates or scales as much as one-eighth of an inch across. Within 3 feet of the pegmatite the biotite scales are coarse, ranging from one-sixteenth to over half an inch in diameter. They are bunched at all angles, and the rock shows but little schistosity. This rock may be called massive biotite.

COLORADO.

FREMONT COUNTY.

Location of mines.—Mica was mined and prospected in Fremont County, Colo., by the United States Mica Co., of Chicago, and others from about 1904 to 1907. The mines are located on the east side of Mac Gulch, a tributary of Currant Creek, about 2 miles south of the Park County line and about 25 miles northwest of Canon City. The Micanite post office was formerly near the mines, but at present it is 3 miles east, on the West Fork of Wilson Creek. The deposits are in rough, mountainous country at elevations of 7,900 to 8,400 feet above sea level. The names and present ownership of all the claims could not be learned. The old Micanite post office and mica shops are in the gulch, and the position of the different workings examined can be described with respect to them. The most northerly working is about three-fourths of a mile north of the shops, in the steep east wall of the gulch, probably 300 feet above the bottom. This working will be called the North mine in the following descriptions. Mine No. 8 of the United States Mica Co., at present claimed by Thomas Pennington and Luther Seymour under the name Climax, is about 250 yards east of south of the North mine in less broken country near the summit of the ridge. Another working, which will be called the East mine in the description below, is nearly a quarter of a mile east of the Climax or No. 8, on the west side of a small gulch tributary to Mac Gulch. Another deposit was opened by the United States Mica Co. on the summit of the narrow ridge east of the shops, about two-thirds of a mile south of the Climax working. This will be called the South mine. Two prospects have been opened by F. L. Rowe, of Micanite, one about 150 yards south of the South mine on the point of the ridge, and the other a quarter of a mile to the southeast, in the east side of the gulch. Still other prospects are reported to have been opened in the region by the United States Mica Co.

North mine of United States Mica Co.—The North mine was worked by an open cut and tunnels in a northerly direction along the steep mountain side. Crosscuts and pits were made on the west or lower side. The open cut is about 100 feet long and of irregular shape. It has a depth of 25 feet in places, but caving of the walls has filled parts of it. The dumps on the mountain side are large.

The country rock immediately around the mine is composed of biotite schist and gneiss with streaks of muscovite schist having a porphyritic texture due to inclusions of small feldspar crystals. The formation strikes about north and dips 35° W. The pegmatite body is probably 30 feet thick and of irregular shape. It cuts the gneiss with an irregular but low dip. The component minerals of the pegmatite are in some places segregated into irregular masses and in others they occur in the usual mixture. Along the west side of the open cut there is a mass of quartz at least 20 feet thick and probably 50 feet long. This quartz is chiefly white, but in places it is pale pink. The pegmatite was richest in mica on the east side of the quartz, but pockets of mica were also mined along the west side and to the north of it. Both pink orthoclase and white albite or other plagioclase feldspar were observed in the pegmatite. Beryl and apatite were noted as accessory minerals. Fragments of opaque bluish-green beryl crystals 5 inches in diameter were found on the dump. Two badly fractured crystals of apatite, about 12 and 18 inches across, were seen in the massive quartz. These crystals were opaque and contained both green and pink apatite. Most of the mica left around the mine was "wedge," "fishbone," and small plates chiefly suitable only for grinding.

Climax claim or mine No. 8.—The Climax claim or working No. 8 of the United States Mica Co. was worked by three open cuts with connecting tunnels, some smaller cuts or pits, and a tunnel at a lower level. The workings fall within an area about 100 feet long from north to south and 50 feet wide, and their positions are shown in the rough sketch (fig. 42).

The lower tunnel is about 15 feet below the level of the floor of the larger open cuts (1 and 2 in the figure). It is about 60 feet long and branches as shown in the end. Open cuts 1 and 2 are from 10 to 15 feet deep and are connected with No. 3, which is at a little greater elevation, by an inclined tunnel or raise.

The country rock is diorite gneiss with streaks of biotite schist and gneiss. The pegmatite dike is probably 25 feet thick and cuts the inclosing gneiss irregularly. In the open cuts it appears to dip 15°–20° E., but the lower contact exposed in the end of the tunnel is irregular and rolling, as shown in figure 42. The pegmatite is coarse grained and has an irregular texture. Parts of it consist of the normal mixture of feldspar, quartz, and mica, but other parts contain large crystals and segregations of these and other minerals. Quartz occurs in masses 10 feet across, feldspar in crystals a yard through, and mica in blocks weighing 50 pounds or more. Imperfect crystals of mica 18 inches across and 6 to 8 inches thick and masses of wedge-shaped crystals 2 feet across had been left exposed in the face of the pegmatite in the open cuts. An unusual feature of this pegmatite, but without economic value, is the inclusion of cordierite crystals or masses, some nearly a yard across, in various stages of alteration. This cordierite occurs in contact with all three minerals

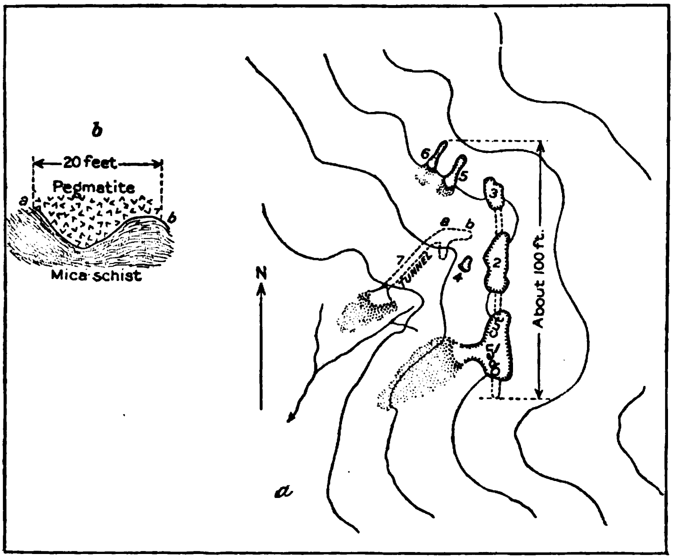

FIGURE 42.—Plan and section of Climax mica claim or working No. 8 of United States Mica Co., 25 miles northwest of Canon City, Fremont County, Colo. *a*, Plan of workings; *b*, cross section in end of tunnel; 1, 2, 3, open cuts; 4, 5, 6, small cuts or pits; 7, tunnel.

of the pegmatite—that is, the feldspar, quartz, and mica. Part of it is fresh and glassy and has a gray to dark violet-blue color in thin pieces. Much of the cordierite has altered to muscovite (often called pinite) and some has been only partly altered. Alteration has taken place along numerous parallel cleavage planes, and the surfaces of these planes are heavily coated with mica. The effect of these numerous cleavages with their reflection from mica-coated surfaces in the glassy cordierite is striking. In some places entire cordierite crystals have altered to masses of brownish-stained mica which still preserve the prominent cleavage planes of the cordierite as thin layers of mica schist with smaller crystals of mica developed between them. Green apatite was found in some of the pegmatite in crystals as much as 2 inches in diameter.

The product of this mine would include both sheet mica and scrap mica for grinding. Many of the large mica crystals have been badly "ruled" and others have imperfections such as the "A" structure and "hair lines." Some of the sheet mica is partly specked with thin films of magnetite between the laminæ. Rough sheets of mica several inches across were seen around the mine, and a specimen was picked from the pegmatite that would cut into clear sheets 2 by 5 inches. There would be a large proportion of scrap mica in trimming the sheet mica and this with the masses of wedge-shaped mica crystals would form an important part of the output of the mine.

East mine.—The East mine was worked by a short tunnel and several small open cuts in an easterly direction down a spur on the east side of a ridge of moderately steep slope. The country rock is coarse biotite granite containing pink or red feldspar. The pegmatite dike is large and is composed of dark-red coarse feldspar crystals and irregular quartz masses with bunches or pockets of small wedge-shaped mica crystals. No mica of sufficient size to cut into sheets was seen at the time of examination, but the wedge-shaped crystals would be suitable for grinding. Biotite mica, a little green apatite, and small fragments of feldspar with bright-green copper stains were seen in the pegmatite or on the dump.

South mine.—The South mine was worked by an open cut with short tunnels near the summit and along the west side of a small knob on a ridge. The open cut is about 45 feet long in a north-northwest direction, 15 to 20 feet wide, and 10 to 25 feet deep. Cross-cut trenches were made at each end of the open cut to the hillside on the west for the removal of waste and ore, as shown in figure 43.

The country rock is coarse biotite granite, characterized by pink feldspar and an abundance of biotite. The pegmatite consists of the usual mixture of quartz and feldspar with mica unevenly distributed through it. The feldspar is dark-pink or red orthoclase or microcline. The pegmatite mass is large and irregular in shape and has streaks of pegmatite and aplite 2 inches to over a foot thick extending from it into the granite below, as shown in the section in figure 43. The pegmatite apparently forms a large bulge or body cropping out at the present surface and surrounded by granite below and on the sides. There seem to be transitional phases between the pegmatite and aplite, and the streaks of these rocks may represent feed channels for the main body of pegmatite or may be offshoots from that mass.

Most of the mica obtained from this mine was small and in wedge-shaped crystals suitable only for grinding. Evidently a large pocket was found, but this was exhausted and considerable exploration work was done in search of other pockets. A little biotite mica was found associated with the muscovite mica in this mine.

Rowe mine.—At the north working of the F. L. Rowe mine an open cut was driven about 35 feet S. 80° E. into the side of the ridge, with a short tunnel and an 18-foot raise to a small open cut above. The biotite granite country rock is cut by two streaks of pegmatite, the upper one 10 feet thick and the lower about 25 feet thick. The west contact of the lower pegmatite strikes N. 25° W. and has an irregular east dip. The pegmatite masses have a very uneven texture and contain segregations of both quartz and dark-pink feldspar 3 to 4 feet across. The mica occurs chiefly in wedge-shaped and "ruled" crystals suitable only for grinding as scrap. Some of it is specked. Several tons of mica was left around the workings.

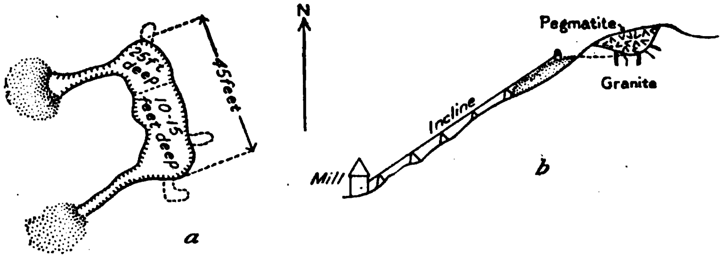

FIGURE 43.—Plan and section of South mine of United States Mica Co., 25 miles northwest of Canon City, Fremont County, Colo. *a*, Plan; *b*, cross section, looking north.

The other prospect of F. L. Rowe, a quarter of a mile to the southeast, was not examined.

LARIMER COUNTY.

Buckhorn mine.—Considerable work was done several years ago by the Buckhorn Mica Mining & Milling Co., about 17 miles in an air line S. 75° W. of Fort Collins, on the North Fork of Buckhorn Creek. The mica deposit lies in an oval-shaped hill elongated in a N. 65. E. direction, about 200 feet higher than and a quarter of a mile south of the camp and mill in the valley below. The elevation of the camp is about 8,000 feet above sea level. Fires have damaged much of the timber, but there is sufficient left on the mountains for mining purposes. A fair road was built from the mine to Masonville, about 12 miles to the southeast, but the bridges and some of the grades are now in bad repair.

The mine was worked by open cuts, two shafts, drifts, trenches, and pits in a N. 65° E. direction along the summit of the hill. The approximate position of the workings is shown in figure 44, in which 1 is a crosscut trench or open cut; 2 an open cut 90 feet long, 10 feet wide, and 2 to 15 feet deep; 3 an open cut 20 feet long and 8 feet deep; 4 a shaft (now boarded up) in the end of a crosscut tunnel; 5 a shaft filled with water within 25 feet of the surface; 6 a crosscut trench 20 feet long and 3 feet deep; and 7 two prospect pits. Drifts were made from the interior shaft 4 on the vein. It was not possible to see much of the underground workings, but the size of the dump indicates that they were rather extensive.

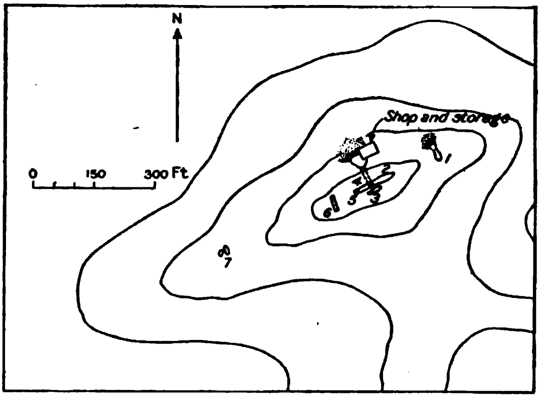

FIGURE 44.—Sketch plan of workings of Buckhorn Mica Mining & Milling Co., 17 miles S. 75° W. of Fort Collins, Larimer County, Colo.

The country rock is chiefly quartz-biotite schist. The pegmatite is approximately conformable with the foliation of the schist, striking about N. 65° E. and having a nearly vertical dip. The contact between the two rocks is sharp. The pegmatite varies in thickness from about 9 feet in the open cut marked 1 to 20 feet in the other open cuts, 2 and 3, and about 10 feet in the prospect pits, 7. It is a variable mixture of gray quartz, albite feldspar, pink orthoclase or microcline feldspar, mica, and a few accessory minerals such as beryl and black tourmaline. The mica occurs in bunches or pockets, some of them several feet thick, in which there is not much gangue mineral, and in separate crystals distributed irregularly through the pegmatite. The pockets are filled chiefly with "wedge," "A," "fishbone," and "ruled" mica in crystals ranging from those of small size to some several inches across. In some of the "A" mica thin plates of albite were observed between the laminæ. Blocks of light-greenish compact massive mica have been thrown on the dumps. This is composed almost entirely of mica in scales of various sizes, some minute and some one-eighth of an inch in diameter, with but few impurities intermixed. Pale-greenish to white beryl crystals several inches across were observed in the pegmatite in the open cut. In places black stains of manganese oxide have penetrated into the seams in the pegmatite. The mica-quartz schist wall rock in one place has been strongly metamorphosed by the pegmatite and much small black tourmaline has been deposited in the bedding planes and through the layers of schist.

The mica from this mine is light green, but very little of it is suitable for sheets. It is of a good grade for grinding for wall-paper decoration, because of its light color and brilliancy. Possibly the fine compact variety mentioned above would be suitable for grinding and might be found in large quantity. No rich pockets of mica were left exposed in the workings, and little idea could be formed as to the yield to be expected. Several tons of good scrap mica had been left on the storage floor of the shop at the mine and several tons more in the bins at the mill.

The mill erected on the property was operated by steam engine and was equipped with dry-grinding machinery. The mica was ground with a Raymond patent pulverizer No. 0 and conveyed to a Barnard & Leas bolter by air draft from a rotary blower. The capacity of the mill was limited by that of the bolter to 1½ tons a day. The pulverizer could have supplied two or more bolters.

Another mica prospect was opened by Parkson & Kitchen about a quarter of a mile west of the Buckhorn mine. The work consisted of an open cut on a bulge of pegmatite nearly 30 feet across. The pegmatite has a northwesterly strike and is inclosed in biotite gneiss. An irregular streak or pocket of mica, about 6 feet thick, extended across the pegmatite in a northeasterly direction. Green and yellow opaque beryl crystals up to 2½ inches in diameter were found. Orange-colored and yellow ocherous stains of uranium were found in a few pieces of pegmatite on the dump. These were reported to surround small cores of a heavy black mineral which might be pitchblende. The mica obtained resembles that of the Buckhorn mine and is practically all suitable only for grinding.

JEFFERSON COUNTY.

Mica has been mined or prospected at several localities in Jefferson County, and two deposits southwest of Morrison were examined. These were the Bigger Bros.' mine, about 9 miles southwest of Morrison, and the Thomas mine, about 12 miles west-southwest of Littleton. These mines are in rough mountain country a few miles west of the first foothills scarp of the Rocky Mountains.

Bigger mine.—The Bigger Bros.' mine is located on the south side of a tributary of Turkey Creek at the edge of a broken plateau about 7,100 feet above sea level. It is about half a mile from a good road along Turkey Creek to Morrison. A passable wagon road could be made to the mine at small expense. The developments consist of a deep shaft with a tunnel from the hillside to an upper level, an open cut northwest of the shaft, and an irregular set of "groundhog" workings to the southeast of the shaft. The approximate positions of the different workings are shown in figure 45. The shaft is reported to be 80 feet deep and was sunk some 30 years ago in search of tin ore. It is filled with water within 30 feet of the surface. The tunnel from the hillside on the northeast is about 50 feet long and only about 15 feet below the surface. It has caved in badly. Other short tunnels were made from the shaft at this level. The open cut to the northwest is about 35 feet long and 10 feet deep. The "groundhog" workings are about 100 feet southeast of the shaft and consist of an irregular-shaped open cut about 20 feet deep with short drifts and rooms.

The country rock is chiefly diorite cut by reddish granite. The pegmatite crops out in a large bed that is nearly horizontal or has a light south dip, forming a small scarp along the edge of the valley, and is therefore in a very favorable position for development by open work or tunnels. The lower contact of the pegmatite is concealed by soil and vegetation, but the bed must be at least 25 feet thick. The shaft cut through pegmatite into the underlying diorite, but at what depth could not be determined. The pegmatite has an exceedingly variable texture, and in places the segregations of the different component minerals are large. Masses of pink orthoclase or microcline feldspar, 8 feet thick, composed of several large crystals, and irregular segregations of quartz, some with a pale rose tint, of similar size, were encountered in the workings. Mica occurs in large aggregations or deposits of "wedge," "A," "ruled," and "fishbone" crystals. These deposits are irregular in shape and range from 1 foot to 8 or 10 feet in thickness and 15 to 20 feet in length. They occur among the large masses of feldspar and quartz. Beryl crystals are abundant and there are probably over 2 tons in sight on the dumps and in the workings. The beryl crystals seen were opaque and ranged from 4 to 18 inches in diameter. Black tourmaline was found in a small pit east

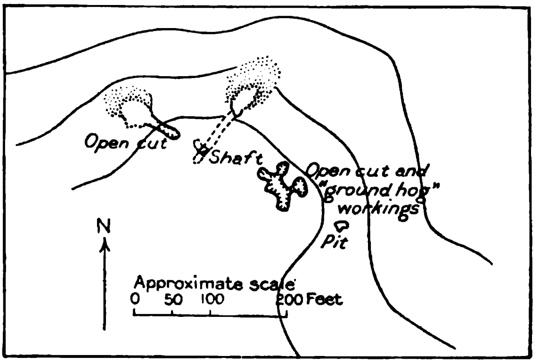

FIGURE 45.—Plan of Bigger mica mine, 9 miles southwest of Morrison, Jefferson County, Colo.

of the main workings. But little muscovite mica was found in the pegmatite at this place, and most of it was associated with biotite mica.

The mica from the Bigger mine is practically all suitable only for grinding. A little small sheet or punch mica might be cut from some of the crystals, but that would be a very small proportion of the production. Scrap mica can be mined in a rather pure form, not requiring much cleaning before shipping or grinding. As long as such large pockets of mica as were exposed in the workings at the time of examination could be found, scrap mica could be mined cheaply.

Thomas mine.—The Thomas mica mine is in the steep slope of the west side of a tributary of Deer Creek, about 1½ miles southeast of the Bigger mine. It has been worked by an open cut 15 to 30 feet wide, extending for a height or distance of about 50 feet in a N. 60° W. direction up the hill, with two short tunnels and a room stoped out near the bottom of the cut. A small cleaning mill had been erected near the lower tunnel.

The country rock is schistose diorite cut by reddish granite. The pegmatite and the inclosing diorite have been partly decomposed. Sufficient work had not been done to expose the attitude of the pegmatite toward the inclosing rock. One contact between pegmatite and country rock had a strike of N. 30° E. and a dip of 70° SE. The schistosity of the inclosing diorite strikes N. 60° W. and has a vertical to high northeast dip. Much of the pegmatite has a rather fine, even grain, but some is very coarse and variable in texture, with large feldspar crystals, masses of quartz, and bunches of mica. The mica obtained is chiefly small, owing to the excessive "ruling" of the larger crystals. Some punch and small sheet mica could be obtained, but the principal returns would be obtained from the scrap mica. The quality of some of the small sheet mica is excellent, the color being a clear "rum" and the cleavage perfect. Among other minerals observed in the pegmatite were numerous opaque red garnets and a little apatite.

Apparently scrap mica was rather plentiful in parts of the pegmatite. Much of the pegmatite was crushed in the upper part of the mill, and the product was distributed by gravity over coarse sieves below, where the mica was separated from it.

CONCLUSION.

Mica is an important mineral in the industrial world, where it meets a demand not supplied by any other material. Sources of supply are therefore of both present and future importance. Many good mica deposits are known in the United States and the production is increasing. The imports of mica are generally greater than the domestic production, but the mica mines of the United States could be made to supply all but that small part of the domestic demand which calls for the softer Canadian "amber" mica. This output could be readily furnished if some of the mines in several States were operated on a large scale, or even as they have been worked in the past. Good mica mines have been worked in North Carolina, New Hampshire, South Dakota, Idaho, New Mexico, Virginia, South Carolina, and Alabama, and promising deposits are known in several other States.

The occurrence of mica deposits in numerous other countries insures future supplies of mica for the world for some years to come, and the many undeveloped mica deposits of the United States may be considered among these resources. Under present conditions the mica deposits of the United States will probably continue to yield a considerable part of the mica used in this country.

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A L Crawford

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GOLD PLACERS
ON
WIND AND BIGHORN RIVERS, WYOMING

BY

FRANK C. SCHRADER

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1913, PART I—G

WASHINGTON
GOVERNMENT PRINTING OFFICE
1914

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GOLD PLACERS ON WIND AND BIGHORN RIVERS, WYOMING.

By **Frank C. Schrader.**

INTRODUCTION.

This paper contains a brief account of an examination of the gold placers on Wind and Bighorn rivers, in Fremont and Hot Springs counties, Wyo., made in connection with land-classification work on the Shoshone Indian Reservation in the autumn of 1913.

For generous aid and information thanks are due Superintendent Norris and Chief Engineer E. E. Jones of the Wind River Indian Agency, to mining men, prospectors, and ranchers in the region, and to E. L. Crabb, surveyor at Shoshoni, for a valuable sectionized blue-print map of the ceded portion of the reservation.

LOCATION AND ACCESS.

The Shoshone (Wind River) Indian Reservation (including the ceded portion), a roughly quadrangular east-west area about 65 miles long by 55 miles wide, lies in the basin of Bighorn River and in that of its tributary Wind River, in central Wyoming, mainly in the northwestern part of Fremont County. (See Pl. I.) It is bounded on the north by Owl Creek, a tributary of the Bighorn, and on the southwest by the Wind River Mountains.

The Wyoming & Northwestern Railway (a branch of the Chicago & Northwestern), whose western terminus is at Lander, runs through the southeastern part of the reservation, with stations at Lander, Riverton, Arapahoe, Hudson, and Neble (formerly Wahaba). Shoshoni, on the same railway, is about 2½ miles east of the reservation. Riverton is a growing agricultural and stock town of about 600 people. Coal is mined on a considerable scale at Hudson and elsewhere, and oil is produced commercially in the region about Lander. All these places are connected by good wagon and automobile roads with Fort Washakie and the Wind River Agency and its mission, which are located near together in the southern part of the area and contain a population of about 2,000. A recently constructed line of the Chicago, Burlington & Quincy Railroad traverses the northeastern part of the area.

The wagon road which ascends Wind River diagonally across the area forms a main highway leading beyond Dubois, a large tie camp of 800 people, to the "big game" hunting ground about the Continental Divide south of Yellowstone National Park, which is but 40 miles northwest of the area. The development of this road into a tourist approach to the park is contemplated. Considerable additional activity has been occasioned in the region by recent irrigation projects, and by the occupation of large tracts of the ceded portion of the reservation recently opened up to settlement.

TOPOGRAPHY.

The area in general slopes and drains toward the southeast, and also from the northeast and southwest toward the master stream, Wind River. On the southwest lie the Wind River Mountains, a high and rugged range which forms part of the Rocky Mountain system and in which rise nearly all the important tributaries of Wind River. On the north are the Owl Creek Mountains, which also are high and rugged, culminating at 9,000 feet above sea level, and which form the western continuation of the Bighorn Mountains. They extend through the northern part of the area and merge into the south end of the Absaroka Mountains in its northwest corner.[1]

Wind River rises on the south slope of the Absaroka Mountains and the adjoining east slope of the Wind River Mountains, just opposite the headwaters of Snake River, from which it is separated by the narrow Continental Divide.[2] It enters the area on the west at Circle and flows through it in a southeasterly direction. Near Riverton it unites with Popo Agie River to form Bighorn River, which flows northward for 50 miles along the eastern border of the area and thence northeastward into Montana, where it joins the Yellowstone, a tributary of the Missouri.

The elevation of Bighorn River in the eastern part of the area, at the head of Bighorn Canyon, where it cuts across the Owl Creek Mountains in a steep-sided trench 2,250 feet deep, is about 4,620 feet above sea level, and the elevation of Wind River at Circle, in the upper or western part of the area, is about 6,600 feet. Along these rivers within and west of the area are numerous fine water-power sites, one of which, in Bighorn Canyon, is utilized by the Boysen dam project, which supplies power, light, and heat to neighboring districts and towns.

The nonmountainous portion of the basin, occupying the greater part of the area, consists principally of broad rolling plains and smaller scattered badland areas, with intermediate erosion forms,

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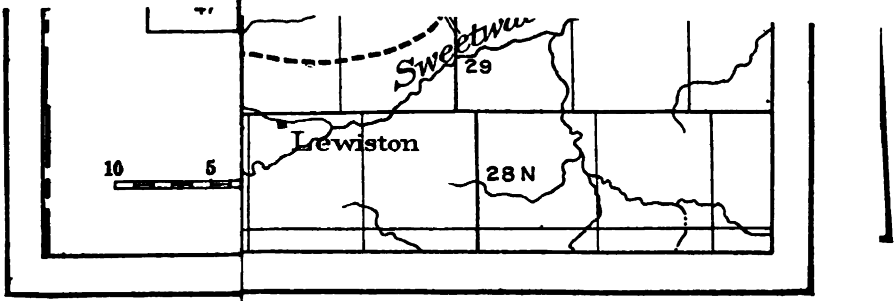
[1] Darton, N. H., Geology of the Owl Creek Mountains: S. Doc. No. 219, p. 10, 1906.

[2] The northwestern part of the area and the adjoining region on the north, northwest, and west are shown on the Kirwin, Younts Peak, and Fremont topographic sheets of the United States Geological Survey.



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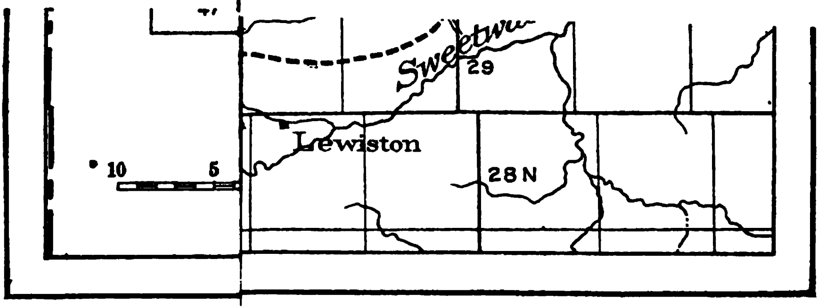

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such as fragmentary mesas, flat-topped buttes, and sharp-crested, steep-sided ridges, separated by valleys and gulches of steep gradient. Conspicuous examples are Boulder Flat, near Milford; Elkhorn Flat, near Fort Washakie; Reservoir Butte, near Shoshoni; Pilot Butte, near Pavilion; and Crow Heart Butte, near Lenore.

The plains rise from Wind River to 6,000 feet above sea level at the foot of the Owl Creek Mountains on the northwest and nearly 7,000 feet at the foot of the Wind River Mountains on the southwest. All the large streams carry excellent clear water and flow with brisk currents in flat-bottomed valleys. Bordering them, in general alternately on either side, are mostly arable level alluvial bottoms or flats. The flats generally lie 4 to 10 feet above the level of the stream. They vary in width from more than a mile on Bighorn River in the eastern part of the area to 100 feet or less along the upper course of Wind River on the west. They are generally followed by wagon roads between settlements and are occupied by ranches.

From the outer edge of the flats the surface rises, generally in a succession of terraces or gravel-covered benches, some of which, as at Riverton and above the mouth of Popo Agie River, are of great width, to heights of 100 feet or more above the river, where they give way to plains and other upland features.

GEOLOGY.

BEDROCK.

The geology of the area, except a belt about 15 miles wide along the southwest and west sides, has already been described, that of the southern part by Woodruff and Winchester[1] and that of the northern part by Darton.[2]

Almost the whole of the central interior or nonmountainous portion of the basin is occupied by the Wind River formation (Eocene), which underlies the plains and in which the valleys and other topographic features are carved. It consists chiefly of gently inclined beds of soft sandstone and sandy shale, in places nearly 2,000 feet in thickness.

Locally, however, as along the crest of the Oil anticline (see Pl. I), the deformed and upturned underlying Upper Cretaceous formations (Mesaverde formation and Mancos shale) make up the country rock. The Mesaverde formation, which consists of about 3,000 feet of sandstone and sandy shale, is the coal-bearing formation of the region.

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[1] Woodruff, E. G., and Winchester, D. E., Coal fields of the Wind River region, Fremont and Natrona counties, Wyo.: U. S. Geol. Survey Bull. 471, Pl. XLIX, p. 528, 1912.

[2] Darton, N. H., S. Doc. 219, Pl. X, p. 24, 1906.

Deep canyons and valleys eroded in the foothills and basal slope of the mountains expose tilted lower Mesozoic and Paleozoic sedimentary rocks of great thickness and in places still older pre-Cambrian granite, gneiss, and schist. Of the Paleozoic rocks certain beds of Pennsylvanian age dipping under the basin are believed to be the chief source of the oil in the Lander field.[1]

ALLUVIAL DEPOSITS.

Distribution.—Deposits of washed gravel or alluvium containing placer gold underlie the lowlands or flats and form the terraces and bars along and in the streams, floor the channels, cap the benches and buttes, and in places blanket the plains, mesas, and uplands for several miles from the present streams and hundreds of feet above them. Prospectors report them present on the uplands 15 miles back from the river.

The deposits vary in thickness from place to place. The most continuous and extensive sheets occur in the flats along the main streams, where, except along the upper courses, the average thickness is 12 to 14 feet, about half of which lies above the river level.

From Arapahoe, at the mouth of Little Wind River, the deposits, including some which are terraced, apparently extend in an almost continuous sheet downstream by way of Riverton to or below Neble, 15 miles distant. In the longitude of Riverton and the mouth of Popo Agie River the sheet is about 4 miles wide, and at several points along Bighorn River bluffs show it to be 15 feet or more thick. At Riverton it has a reported thickness of 12 feet, and at Neble of about 22 feet.

The maximum thickness found in the present investigation is on a bench in a cut on the Chicago, Burlington & Quincy Railroad on Bighorn River just above the head of Bighorn Canyon, where about 60 feet is exposed. A thickness of 15 feet caps the isolated butte on which the Shoshoni town reservoir stands, nearly 2 miles from the river and 400 feet above it. The average thickness of the deposits that blanket the more extensive mesas and uplands is estimated at 5 to 8 feet.

Character and composition.—The deposits are composed mainly of rounded, waterworn material. They consist of a heterogeneous mixture of granite, quartzite, sandstone, limestone, slate, dark and light volcanic rocks, schists, gneissoid pebbles, sands, and clay. They contain also pebbles of nodular chert and chalcedonic material. In general, bluish and bluish-gray quartzite is noticeably abundant in the gravels in and near the eastern border of the area, especially on the benches and uplands extending from the head of the Bighorn

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[1] Woodruff, E. G., The Lander oil field, Wyoming: U. S. Geol. Survey Bull. 452, p. 10, 1911.

Canyon southward along the east side of Bighorn River beyond the latitude of Shoshoni and Reservoir Butte. Pebbles of volcanic rocks, mostly dark, apparently derived from the volcanic areas of the Absaroka and adjoining Owl Creek mountains, are conspicuous at Circle in the gravels discharged from the northwestern part of the area by Dry and Crow creeks and by North Fork of Wind River. Many of these pebbles are elongated, flattish, spatulate, or wedge shaped.

The deposits in general are crudely and coarsely stratified, indicating rapid deposition by swift currents. Rarely are they well stratified or banded. Most of the deposits are loose or unconsolidated, but in some places they are firmly cemented into a conglomeratic mass, as opposite Hudson on Popo Agie River (locality 97, Pl. I), and on Wind River at the ford below the new county bridge above Lenore (locality 61). Such deposits would have to be quarried by blasting and passed through a crusher or mill before they could be sluiced or treated by ordinary placer methods. Consolidation seems to be more common in the bench deposits, as at Hudson, than in those immediately along the present streams. The cementing material consists mainly of carbonates of lime and iron and hydrated iron oxide.

On the lower stretches of the Bighorn in the eastern part of the area the gravel is of medium size, but farther upstream it is coarse and bowldery, as at the old mill near Milford, on North Fork of Popo Agie River.

On Dinwoody and Bull creeks, on the upper part of Little Wind River, and on North Fork of Popo Agie River the washed gravel gives way to very coarse glacial morainic material, through which for miles the rivers in large part tumble over beds of bowlders several feet in diameter. On Little Wind River the moraine is well developed and extends down eastward within a few miles of Fort Washakie. On Bull and Dinwoody creeks the morainal deposits extend to Wind River, where during glacial time the glacier apparently crowded the river to the opposite side of the valley against the bluff.

Contained in the washed gravel is an unusual amount of sand, including considerable quicksand. The abundance of the sand is due chiefly to the arenaceous character of the formations from which much of the gravel is derived and especially to the Wind River formation, on which it mostly lies. The sand is much more plentiful in the eastern or lower part of the stream course than in the upper part. On the Bighorn it occurs in beds of relatively pure sand 4 or 5 feet in thickness and of considerable extent.

The sand is mostly coarse, but much of it is fine, and with this portion the gold, as small particles or "colors," is chiefly associated. The fine sand contains also much magnetic garnetiferous and zirconiferous material. In the pannings or concentrates from locality

86 (see Pl. I), about 2½ miles southwest of Arapahoe on Popo Agie River, about 90 per cent of the sand, 22 grams in weight, was found to be magnetite or strongly magnetic, and about one-fourth of the remaining 10 per cent to be feebly magnetic, being apparently titaniferous magnetite, ilmenite, or chromite. Of the nonmagnetic portion of the sand, about two-thirds is pink zircon and the remainder is apatite, ilmenite, garnet, epidote, and other heavy minerals. A few small perfect octahedra, which seem to be spinel, are present.

The sand grains are chiefly subangular or but partly rounded, and most of them, especially those in the magnetic portion, average about 0.3 millimeter, or one-eighth of an inch, in diameter. Some of them are as small as 0.1 millimeter or even smaller. The nonmagnetic grains are smaller than the magnetic, averaging about 0.25 millimeter, or 0.01 inch, in diameter and ranging down to 0.1 millimeter or less.

In the concentrates from locality 99 (Pl. I), on Beaver Creek 3 miles east of Arapahoe, the sand, 5 grams by weight, is a little finer than that from locality 86 but contains some grains which are much larger than any in sample 86. Slightly more than 50 per cent of the sand is magnetite or strongly magnetic, and the remainder, which is gray-brown or "ruby," contains some feebly magnetic material, mainly titaniferous magnetite, ilmenite, or chromite. The magnetite averages about 0.25 millimeter in diameter, but about 10 per cent of the grains are larger and many are much smaller, some 0.08 millimeter or even less.

The nonmagnetic portion of the sand, as in sample 86, is finer than the magnetic. It averages from 0.15 to 0.2 millimeter in diameter and consists chiefly of pink, reddish, or amethystine-colored zircon, a little green epidote and apatite, and a few grains of a brownish mineral resembling monazite. The magnetite and garnetiferous constituents of the sand are probably derived chiefly from the old schist rocks, the zircon, apatite, and epidote from the granite, and the ilmenite from basic volcanic rocks.

On Crow Creek the deposits are said to contain an unusually large amount of black sand, most of which is probably derived from the dark volcanic rocks of the Absaroka Mountains and the adjacent part of the Owl Creek Mountains at the head of the creek.

Origin and age.—The deposits are fluviatile in origin. Those on the benches, buttes, mesas, and uplands were deposited by rivers flowing at higher levels, and they are accordingly older than those now being formed. Some of them probably date back into the Tertiary, but they have not been differentiated in this examination.

MINING DEVELOPMENT.

GOLD LODES.

Mining exploitations in the area are few but widely distributed. Apparently the most important are those of the Owl Creek and Willow Creek districts, in the northeastern part of the area. (See Pl. I.) Both districts produce or contain gold and silver in quartz veins in pre-Cambrian granites and schists. In the Owl Creek district, however, copper predominates over the precious metals.

Several years ago, at the southwestern border of the surveyed part of the area, about 3 miles within the mountains, at locality 75, on St. Lawrence Creek, a north-side tributary of Little Wind River, some quartz prospecting was undertaken at intervals extending through several years by a prospector named Hobbs, whose forge and mining tools still lie at the mouth of the creek.

Here Little Wind River and its tributaries have cut through a great thickness of tilted and faulted Paleozoic rocks and have sunk deep into the underlying older granite and schist floor. For half a mile or more at the junction of St. Lawrence Creek, which descends the rugged northwest slope of the basin in a series of cascades through a gorge nearly 200 feet deep, the canyon is widened, and in this portion it is known as the St. Lawrence Basin.

The Hobbs prospect is located mainly on the south side of the creek, 100 to 200 feet above it. It is not easy of access. It consists, broadly speaking, of steeply northward-dipping coarse granitoid or pegmatitic dikes or veins intruded into reddish and dark or blackish granite and schist. Contained in or associated with the dikes are lenses, stringers, and irregular bodies of quartz 2 to 4 feet in width and of considerable extent. Locally other minerals, notably the feldspar and biotite, are segregated into similar bodies, bands, and streaks.

It is probable that some of these dikes or veins contain a little gold, but apparently not in workable amount. The quartz in general is of the barren glassy-looking "bull quartz" variety. If gold were present in commercial amount it would naturally be found in the gravels of Little Wind River below the prospect, but this is not the case. The gravels of Little Wind River are much leaner in placer gold than those of either Wind River on the north or Popo Agie River on the south.

If the vein-forming intrusive rocks of the prospect cut the overlying Paleozoic limestone, a point which was not investigated in this examination, the more likely place to look for mineral would be in the limestone in association with the intrusives.

GOLD PLACERS.

The deposits which have attracted most attention are the gold placers, which have been exploited in a small way from time to time for the last 50 years, but never successfully, according to accounts of pioneers whose observations cover the period.

In 1910 a placer excitement or boom prevailed in the Wind River country, and all the available ground on the main streams in the area, especially on Bighorn and Wind rivers, was staked and held until the recent failure of the Neble dredge, when the claims were nearly all abandoned. Among the more important exploitations begun during this activity were those of the Riverton Mining & Dredging Co., of Indianapolis, Ind., about 7 miles west of Riverton on Wind River, and those of the Shoshoni Gold Dredging Co. on Bighorn River 3 miles southwest of Neble, at locality 24. (See Pl. I.)

Dredges have been in operation at both of these localities, but neither of them has been successful, owing apparently to the difficulty of separating the gold from the large amount of heavy sand with which it is associated.

The Neble dredge of the Shoshoni Gold Dredging Co. was a large modern well-equipped plant of Marion make, but the project was abandoned as nonworkable after six weeks' trial, and at the time of visit the plant had been sold, dismantled, and nearly all removed to Taylor Park, Colo., by the Tin Cup Gold Mining & Dredging Co. The dredge was operated by electric power transmitted from the Boysen plant, 25 miles to the north, in Bighorn Canyon.

During operation a large amount of gravel, said to have averaged about 28 cents in gold to the cubic yard, was treated; but the gold could not be saved in paying quantities. The best results are said to have been obtained by collecting the gold on a cocoa mat with steel riffles. Prior to the installation of the dredge only very preliminary tests, consisting chiefly of six drill holes, are said to have been made. After the trial a set of drill holes extending across the river near localities 25 and 26 (Pl. I) are said to have been sunk by the company and to have shown no pay.

The deposits at this place are about 22 feet in maximum thickness. They extend from the surface at 4 or 5 feet above the river level to 17 feet below it. The bedrock floor on which they rest is very uneven but consists of soft sandstone physically favorable for dredging, as the top foot or more is easily scraped up by the buckets, thus avoiding loss of gold in bedrock crevices and cavities. It seems likely, therefore, that temporary and shifting bars, like those that have sporadically concentrated values at certain localities on Snake River, may have misled the prospector and the company.

The dredge of the Riverton Mining & Dredging Co. has been in operation at intervals for several years, but, like the Neble dredge, it has not been successful in saving the gold in paying quantities, although the gravels treated are reported by the company to have averaged 76 to 80 cents to the cubic yard, and the concentrates during a part of the time were treated by a Wilfley table plant, which was located on the shore to maintain perfect equilibrium in operation. Recently, however, the company believes that it has discovered a more efficient process, that of the Richards pulsating jig, for saving the gold, and it has leased about 10 miles of the adjoining lowland along the river, on which it plans to continue operations in 1914.

At the upper end of the tract, just above locality 43, on the north side of the river, a Minneapolis company is said to have done considerable work, with apparently good showings, several years ago; but it finally discontinued operations abruptly and, so far as learned, made no production.

Other important localities at which placer ventures have been undertaken are on the Bighorn west of Shoshoni, on the eastern border of the area, and on Dinwoody, Dry, and Meadow creeks, in its western part. Some prospecting has also been done up Crow Creek, but without favorable results.

The deposits near Shoshoni are contained in a belt about 3 miles long and one-third mile wide, extending from the vicinity of the wagon bridge at the mouth of Poison Creek northward to or beyond Badwater Creek. Here various machines, appliances, and devices, including blanket processes, were tried in the effort to save the gold, but apparently the best of them were found to be only partly successful. None were able to save enough of the gold to encourage continuation of operations, although much of the ground from Badwater Creek up the river, and particularly on the Libby ranch, is said to average 75 cents in gold to the cubic yard. The gravel sheet, as shown by surface wells sunk for domestic use, exceeds 12 feet in thickness. Its surface is 4 to 9 feet above river level. None of the prospects or wells sunk in the belt extended to bedrock. On the Olsen ranch, however, about half a mile below Badwater Creek, a well sunk through the deposits found bedrock at a depth of 20 feet.

Some of the gravel in the southern third of the belt, extending from the Sidenbender farm southward to the bridge road, looks well and contains considerable gold, which, however, is mostly very fine and is associated with large amounts of sand.

On Dinwoody Creek, on the west, below the outlet of the lake, the placers are said to have been unsuccessfully exploited several years ago, extensive sluices and a pipe line and other equipment being installed.

Near Riverton the placer rights from the railroad for several miles westward along Wind River are owned or controlled by the Arapahoe Gold Placer Mining Co. This company reports having sunk a curbed shaft to bedrock in or near the present river channel and found considerable gold in the potholes or cavities in the bedrock sandstone. Half a pint or more of the concentrates, consisting mainly of black and ruby sand and containing some fine gold, was shown to the writer. The company apparently has great hopes of the placer possibilities of the ground. However, several tests made in the course of this examination, on gravels next to bedrock on the bench overlooking the river, gave only a few small colors of fine gold, which are not indicative of the workability of the deposits.

GOLD IN CONTIGUOUS DISTRICTS.

Beyond the borders of the area here treated, in the region more or less immediately surrounding it, the nearest mining developments are those of the Clark, Atlantic, New Pass, Miner's Delight, and Copper Mountain districts.

In the Clark district, about 25 miles beyond the northwest corner of the area, 10 miles above Dubois and about the same distance east of the Fremont County line, Clark's placer mines on Warm Spring Creek, a south-side tributary of Wind River, are reported to have produced a little gold. The same is apparently true of one or two north-side gulches farther up the river.

The Miner's Delight, Atlantic, and South Pass districts are, respectively, about 20, 23, and 25 miles south of Lander. The Miner's Delight district is on the near side of the divide on the head of Beaver Creek, and the Atlantic and South Pass districts are just over the ridge opposite the heads of Beaver Creek and Popo Agie River, on Rock Creek and a neighboring parallel stream, both short tributaries of Sweetwater River, which flows eastward into the North Platte. Here gold was discovered in 1842, and several mines have been worked for many years with a credited production of more than $5,000,000 in lode and placer gold.[1] The lodes, which are apparently the source of the placer deposits, occur in and are associated with quartz veins and basic dikes and intrusives mainly in Algonkian schists, slates,[2] and a complex of these and other metamorphic pre-Cambrian rocks and are said to present much similarity to the gold-bearing veins of the southern Appalachian States.[3]

In the Copper Mountain district, at the Birds Eye and Depass camps, respectively about 5 and 10 miles east of the northeastern corner of the area, the deposits, chiefly copper and silver, are contained in pre-Cambrian granite and Paleozoic sedimentary beds cut by basic dikes. These camps have been the scene of considerable development work and for several years have been moderate producers. They should be benefited by the new line of the Chicago, Burlington & Quincy Railroad which was recently completed near by on the west.

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[1] Swarthout, A. H., Mining in Wyoming: Min. Science, vol. 64, pp. 464 et seq., 1911.

[2] Trumbull. L. W., Atlantic City mining district: Wyoming Geol. Survey Bull. 7, ser. B, p. 82, 1914.

[3] U. S. Geol. Survey Mineral Resources, 1905, p. 229, 1906.

THE GOLD.

Occurrence and distribution.—The gold is widely distributed in the river gravels or alluvial deposits, with which it is in general coextensive. It is present in the deposits, on the buttes and uplands, as well as in those of the bars, flats, and channels of the present streams. It is also sparingly present in the glacial moraine deposits.

It is scarcer on Little Wind River, North Fork of Popo Agie River, and the upper part of Wind River between Lenore and Circle than it is on Wind River between Lenore and Riverton or on Bighorn River. This variation is seemingly due in large measure to local suspension of or decrease in the concentration of the gold and the gravels by the streams during glaciation, when the lean areas named were occupied by ice and received only coarse glacial débris. The relative scarcity of the gold between Lenore and Circle suggests that Crow Creek and Sand Coulee or Draw on the north and Dry and Meadow creeks on the south may be important contributors of colors to the deposits.

It is not likely, as held by some, that on Little Wind River the gold occurs only below the Oil anticline near Fort Washakie, above which the river flows chiefly through a glacial moraine. Gold was found in the moraine on Wind River and on the North Fork of Popo Agie River, and it seems extremely probable that gold is also present on Little Wind River in deposits which, owing to their very coarse bowldery character, were not examined in this work.

In the fluviatile deposits along Wind and Bighorn rivers the gold seems to be more plentiful in some localities, as at Neble and Shoshoni, later described, than in others. As no appreciable amount of the gold has been derived from neighboring tributaries the concentration of the gold in these areas seems to be due chiefly to a favorable condition of the currents, influenced by the river gradient and the quantity of tributary gravels discharged into the area.

In any given locality the gold in the fluviatile deposits is widely distributed, occurring in the upper and middle parts as well as in the lower part of the section. In places it seems to tend to accumulate on or near bedrock, but it does not do so constantly nor uniformly enough to encourage bedrock exploitation, though the soft or unconsolidated sandstone of the bedrock is admirably adapted both for its accumulation and for its reclamation by dredging. More than 16 per cent of the samples tested—those from the well-distributed localities 1, 2, 8, 10, 15, 19, 21, 22, 28, 33, 34, 36, 37, 74, 81, 97, and 98—were taken from bedrock or from deposits that extended to bedrock.

Considered more closely at any given locality, the gold is irregularly, not to say sporadically distributed, its deposition having been dependent on the varying strength, velocity, and shifting of the currents of the streams by which it was deposited.

Character.—The gold is bright and has a deep-yellow color. It is finely divided and occurs mainly in small, thin, elongated, flat lamellar tablet-like pieces or particles very much smaller than the head of an ordinary pin, and in this respect it is or stands near to flake gold. When dry, most of it will float on the surface of water, and, owing to this and to the large amount of heavy sand with which it is associated, it is difficult to save. It requires about 350 normal-sized colors to make a cent, not counting the flour or dustlike particles and some coarser intermediate forms which are lost during operation.

Micromeasurements made of the extreme sizes in samples collected from locality 86, on the lower part of Popo Agie River, and from locality 99, on Beaver Creek, show the pieces to range in mean superficial diameter from 0.0125 inch, or 0.312 millimeter, to 0.017 inch, or 0.44 millimeter. At locality 99, on Beaver Creek, where the sample collected contained nine colors, the pieces range from 0.065 inch, or 0.17 millimeter, to 0.025 inch, or 0.6 millimeter. As these figures indicate, the gold is decidedly coarser on Beaver Creek than on the adjoining part of Popo Agie River. The Beaver Creek gold examined is also distinctly elongated.

Measurements of the thickness of the gold lamellæ or flakes, notably of those from locality 86, gave about 0.04 to 0.08 millimeter, with an average of 0.06 millimeter, or 0.0024 inch. Like the river gravel and sand, the gold is progressively finer downstream, and by the time it reaches locality 86, on the Bighorn, in the eastern part of the area, it has been so rehandled by the currents and milled between the gravels that much of it is reduced to a flour whose particles are scarcely visible to the unaided eye. In this respect much of it resembles the flour gold on Snake River in Idaho.

Glaciation or grinding on bedrock beneath the ice mass in and near the mountains has probably also helped to abrade and pulverize the gold.

Above Dubois, west of the area, on the head tributaries of Wind River, prospectors report some of the gold to be coarse, the largest pieces being about half the size of a wheat grain. Extensive inquiry, however, failed to disclose any samples of placer gold from that section or from any part of the Wind River basin, except that controlled by the Arapahoe Mining Co. (See pp. 135–136.)

Both the gold and the containing gravel show extensive wear and abrasion from travel, denoting that they have been transported considerable distances. Much of the gold is marked, dented, and scratched. The corners and edges are mostly worn and rounded, and some of them are curled as if they had been beaten with a small hammer.

Source.—The source of the gold in the gravels of Wind and Bighorn rivers could not be definitely determined, for field work did not extend much beyond the limits of the Shoshone Reservation. It seems certain, however, that here, as in most other placer fields, the gold, like the gravel deposits in which it occurs, was derived by erosion and disintegration from the rocks in the mountains about the basin, especially from those on the west or Rocky Mountain side. Furthermore, the occurrence of gold-bearing lode deposits in nearly all the deep-mine developments both within and surrounding the area points strongly to the quartz lodes, veins, and stringers in the pre-Cambrian granites and schists and in the complex of these and associated rocks as the chief source of the gold.

This view is supported by the fact that the gravel deposits of Beaver Creek and the main fork of Popo Agie River, which head in the vicinity of the Miner's Delight, Atlantic, and South Pass districts, are much richer in gold than neighboring streams which do not similarly head in or traverse these known gold-bearing pre-Cambrian rocks. Also, miners who have worked in the Atlantic and South Pass districts report that the gold in both the lode and placer deposits, like that in the Wind River placers, is very fine—so fine that much of it can not be saved.

On the north, besides the mine developments cited, quartz containing flakes of visibly free gold has been reported from the Owl Creek Mountains, and portions of the granite and associated schists are considerably mineralized and contain veins and impregnations of rusty quartz with gold, iron pyrites, and other ores and sulphides.[1]

To the west native gold occurs in the volcanic rocks in the Kirwin region,[2] and it seems probable that similar auriferous rocks may exist in the great volcanic Absaroka Range, immediately west of the Owl Creek Mountains, and that these rocks have supplied the gold as well as the volcanic gravels on Crow Creek and North Fork of Wind River.

Likewise, on the upper part of Wind River the placer gold in the Clark district and other exploited gulches to the west seems to be derived from prominent quartz ledges reported to crop out extensively in the granite and schist at the headwaters of the river.

In Lincoln County, 80 miles west of the area, on Horse Creek, a west-side tributary of Green River, the placer gold was probably derived from rocks of Jurassic age.[3] Traces of flake gold are also said to occur in shale of Benton age (Upper Cretaceous) in that county. Rocks of both these ages are present in the Wind River basin and the surrounding mountains, and they may possibly contribute to the gold in the area, though so far as learned no gold has yet been found in them in this area. Very likely some gold is disseminated in all the formations of the basin that contain sediments derived from the gold-bearing lodes and rocks in the surrounding mountains. The minute size, thinness, and abundance of the colors favor the wide diffusion of the gold.

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[1] Darton, N. H., Geology of the Owl Creek Mountains: S. Doc. No. 219, pp. 10-34, 1906.

[2] Hewett, D. F., The ore deposits of Kirwin, Wyo.: U. S. Geol. Survey Bull. 540, p. 128, 1914.

[3] Schultz, A. R., Gold developments in central Uinta County, Wyo., and at other points on Snake River: U. S. Geol. Survey Bull. 315, p. 74, 1907.

METHODS OF EXAMINATION AND RESULTS.

As it is only in the bars and deposits underlying the flats along and in the main streams that the deposits have been exploited or seem worthy of exploitation it was here that the examination was chiefly made. Excavations were made in the gravels underlying the lowlands or flats (see fig. 46) at intervals of about 2 miles along nearly 200 miles of river—mainly on the Wind, Bighorn, Little Wind, Popo Agie, and North Fork of Popo Agie. The deposits were also inspected and studied so far as possible while en route from place to place, and the results are believed to give approximately the average gold tenor of the alluvial ground over which the tests are distributed. This belief is supported (1) by the fact that the alluvial flats from which the samples were taken were naturally distributed by the meanders on both sides of the stream; (2) by the general uniformity of results obtained throughout the field as a whole; and (3) by the fact that, though only a little more than 16 per cent of the tests extended to bedrock, the results, together with the reports of leading companies and prospectors who have operated in the field, indicate that this is unimportant, for in general there is no appreciable concentration of gold on or near bedrock.

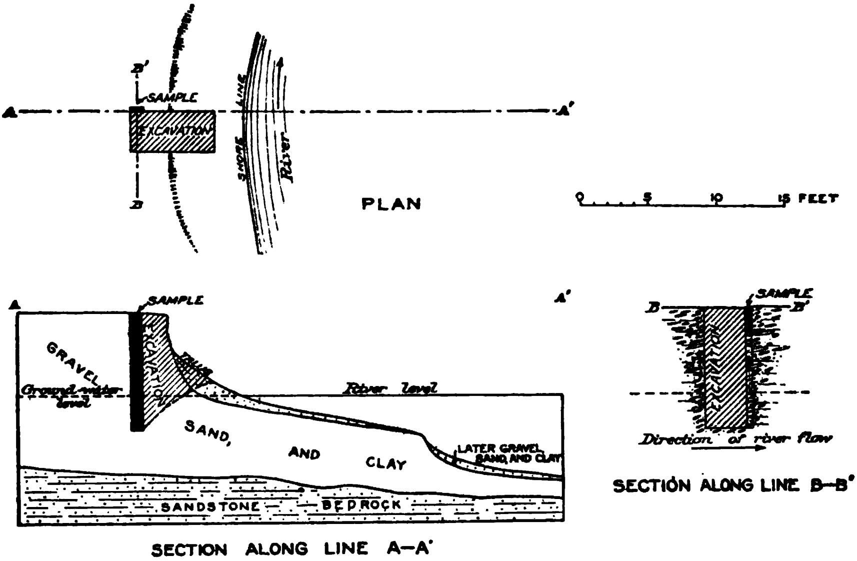

FIGURE 46.—Diagrammatic plan and sections of one of the gold-placer deposits on Wind and Bighorn rivers, Wyo., showing general location of sample and method of taking it.

In selecting the locality for any individual test, stress was laid, next in importance to the occurrence on bedrock near the level of the stream, on the presence of substantial bodies of gravel of considerable acreage and relative permanence, as indicated by standing trees 15 to 20 years old. Thinner, sporadic, temporary, shifting bars in the present stream channels, which vary with almost each flood season, were in general avoided.

The sample taken generally extended from near the surface, 5 or 6 feet above the level of the adjoining stream, to 2½ or 3 feet below it. (See fig. 46.) In some places, however, where the meander of the river had transgressed the lower flat or first bottom and had cut into the front of the next higher terrace or second bottom bounding its outer edge, advantage was taken of the fact to obtain a vertical section rising 20 feet or more above the river. Locality 81, on the Eagle Head ground on Little Wind River below Fort Washakie, is an example of such a place.

Owing to the large amount of territory to be covered in a relatively short time and at moderate expense, most of the samples were obtained by combining a pit with an excavation in a stream-eroded bank. (See fig. 46.) This method is peculiarly adapted to the region where extensive and well-distributed stretches of freshly cut bank adjacent to the stream are plentiful.

The section along the line B–B′ (fig. 46) shows the position of the sample in the downstream side of the cut next to and at right angles to the face. The sample was taken in undisturbed gravels at supposedly sufficient depth to be beyond the effects of frost action. To obtain an equivalent sample by the pit method alone, excavating from the surface down, would require about four times as much time and labor.

The sample was taken from the side instead of the face of the cut in order that it might be at right angles to the currents which deposited the gravel and thus crosscut as much of the deposits as possible. Owing to the generally flat and elongated shape of the pebbles and their imbricated attitude, with dip upstream, the best results are obtained by taking the sample on the downstream side of the cut, so that the inclination of the gravel toward the operator may prevent the escape and loss of much fine material, which would otherwise tend to run down the dip away from the operator into the bank.

The upstream dip of the gravel, together with the general downstream inclination of the bedding of the deposits, is also important in distinguishing gravel in place from talus, slumped, or more recently deposited material.

The sample is most expeditiously and economically collected by working from the base upward in order that any material which may cave during the operation need not be removed from the pit.

From the openings thus made samples of the gravel, ranging from one to twelve pans, were tested at each locality. In general, each pan of gravel treated represents about 1½ feet of the vertical section examined. After panning, the concentrates were examined for gold, generally with a pocket lens as well as with the unaided eye, the size and number of the colors being noted. Some of the concentrates from well-distributed localities (Nos. 12, 14, 24, 25, 26, 43, 61, 70, and 72), aggregating nearly 10 per cent of the whole, were also assayed as a check on the examination by eye. These samples included not only those known to be auriferous, but also some in which no trace of gold was visible, even with a lens, the object being to guard against the possible oversight of any gold discolored by coating. Negative results in the assays of such samples indicate that little or no coated gold, such as is found on Snake River in Idaho, is present in this field.

On the Bighorn at several adjoining localities (Nos. 23 to 26, inclusive), about 3 miles above Neble and 2 miles above Kirby Creek, gravels recently exploited by the Shoshoni Gold Dredging Co.'s dredge seem to contain enough gold to render them workable under reasonably favorable conditions. Two of the samples, Nos. 25 and 26, which assayed 27 cents and 32 cents per cubic yard, respectively, were taken near the surface of a bar about 3 feet above the level of the river. The gravels at this point are said by Mr. Walker, who is familiar with the ground, to extend 22 feet to bedrock and to contain about 28 cents per cubic yard all the way down, except where interrupted by a couple of layers of coarse sand. Similar though not quite so good results as the above were obtained a little farther down the river, at localities 23 and 24, from gravels about 4 feet above the river in the banks of the dredge pond.

The relatively rich bars and gravel found at localities 23 to 26, inclusive, are reported to extend downstream nearly to Neble and to underlie the flats on the south side of the river. On the strength of these reports and the results obtained in the tests the area west of Neble, for several miles along the river, is regarded as being of possible value for placer gold.

In most of the Neble area the gravels apparently extend from near the surface, 7 to 8 feet above the river, to bedrock, about 8 feet below river level, giving for the gravel sheet in general a thickness of about 15 feet. In the portion of the area dredged the surface underlain by the gravel stands about 4 feet above the river, and the top of the underlying soft sandstone bedrock floor, which was found to be very uneven or holey, varies from 4 to 17 feet below river level. The existence of dredgible pay streaks which can be followed for any considerable distance seems unlikely.

The next best results were obtained at locality 99, on a bar in Beaver Creek about half a mile above the mouth. The sample extended vertically from 6 inches above to 2½ feet below creek level. It contained six colors of gold to the pan, giving an average value to the deposit of 33.5 cents per cubic yard. But it is not workable, owing to its small lateral extent, its lack of sufficient water, and more especially its sandy nature. The deposit consists chiefly of coarse gray or bluish-gray sand, mostly quicksand, with a small admixture of fine gravel. If deposits normally clean, containing less sand and fine gravel, occur toward the head of the creek, they would seem to commend themselves to the prospector, particularly since the creek appears to head in the Atlantic City-Miners Delight mineral belt. However, water is reported to be not plentiful during most of the year.

Favorable results, so far as the amount of gold is concerned, were also obtained at locality 43, on Wind River, about 15 miles above Riverton. The gravel underlies a considerable area that rises about 4 feet above the river and is dotted with groves of cottonwood trees 10 to 12 years old. However, the large amount of sand present and the unfavorable results obtained by the work of the Minneapolis Co. a short distance upstream on the opposite side of the river in similar ground cause the deposits to be regarded as unworkable.

CONCLUSION.

The small area at Neble possibly carries placer gold in valuable amounts. Outside of this area, however, the deposits examined, taken as a whole, average less than 6 cents to the cubic yard, and none of them, except those at locality 49 (see Pl. I), exceed 20 cents to the cubic yard, as is shown in the following table:

Thickness, character, depth, and gold content of deposits sampled.

Locality and sample number.	Section.			Depth below surface.	Value of gold content per cubic yard of gravel.
		Ft.	*in.*	*Feet.*	*Cents.*
1	Gravel		2½	[a] 60	2.25
2	do		2½	[a] 50	2.25
3	Sand and gravel	1	6	3½	.00
4	Sand	2	0	8–10	.00
5	Sand and gravel	1	6	10	3.00
6	do	1	0	8	4.00
7	Gravel	2	0	6– 8	7.50
8	do		2	[a] 12	7.00
9	Sandy gravel	1	6	6– 7	.00
10	Gravel		2½	[a] 10	4.50
11	do	2	0	9	9.00
12	Gravel (on bar)	1	0	1	[b] 3.50
13	Gravel	3	0	6	18.00
14	do	1	6	3	[b] 4.00
15	do		3	[a] 6	16.00
16	do	1	6	5	9.00
17	do	2	0	6– 8	.00
18	do	1	0	5– 6	.00
19	do		3	[a] 8	4.50
20	do	2	0	4– 6	4.50
21	do		4	[a] 10	6.00
22	do		2½	[a] 15	.00
23	do	2	0	3	22.50
24	do	1	6	4	[b] 15.00
25	Gravel (bar)	2	0	1– 3	[b] 27.00
26	do	1	6	1– 2½	[b] 32.00

[a] On or extending to bedrock.

[b] Assay return.

Thickness, character, depth, and gold content of deposits sampled—Continued.

Locality and sample number.	Section.			Depth below surface.	Value of gold content per cubic yard of gravel.
		Ft.	*in.*	*Feet.*	*Cents.*
27	Gravel	2	0	8	0.00
28	.....do		3	[a]12	.00
29	.....do	3	0	7	20.00
30	.....do	4	0	6	15.00
31	Gravel (bar)	1	6	2	.00
32	Black loam, sand, and gravel	2	0	4	.00
33	Gravel		3	[a]11	.00
34	.....do		3	[a]8	15.00
35	.....do	9	0	1 -10	9.00
36	.....do		2½	[a]15	.00
37	.....do		2½	[a]10	4.50
38	.....do	3	0	7	15.00
39	.....do	1	6	3½	.00
40	.....do	3	0	9	7.50
41	.....do	2	6	9	.00
42	Coarse sand and gravel	2	0	6	9.00
43	Gravel	6	0	1 - 7	[b]18.00
44	.....do	3	0	3 - 6	.00
45	.....do	2	0	2 - 4	10.50
46	.....do	1	6	1 - 2	4.00
47	.....do	7	0	½- 7½	9.00
48	.....do	2	0	2 - 4	4.50
49	.....do	3	6	2 - 5½	15.00
50	.....do	5	0	2 - 7	.00
51	.....do	5	0	1½- 6½	10.50
52	.....do	4	0	1½- 5½	18.50
53	.....do	2	0	16 -18	9.00
54	.....do	3	6	3 - 6½	8.00
55	.....do	5	6	1 - 6½	.00
56	.....do	1	0	1 - 2	.00
57	.....do	4	0	1 - 5	.00
58	.....do	5	0	1½- 6½	7.50
59	.....do	7	0	1 - 8	5.00
60	.....do	4	6	2½- 7	4.00
61	.....do	9	0	½- 9½	[b]2.25
62	.....do	5	0	1½- 6½	4.00
63	.....do	8	0	1 - 9	2.25
64	.....do	2	0	3 - 5	4.50
65	.....do	2	0	1 - 3	.00
66	.....do	3	0	2 - 5	4.00
67	Gravel and sand	5	0	1 - 6	.00
68	Gravel	8	0	1 - 9	.00
69	Gravel (moraine)	15	0	0 -15	.00
70	Gravel	6	0	1 - 7	[b].00
71	.....do	7	0	3 -10	.00
72	.....do	6	0	1 - 7	[b]7.50
73	.....do	6	0	2 - 8	1.50
74	.....do		3	[a]5	.00
75	Lode deposits probably containing a little gold.				
76	Gravel	5	0	2 - 7	.00
77	.....do	6	0	2 - 8	.00
78	.....do	2	0	2 - 4	.00
79	.....do	10	0	2 -12	.00
80	Coarse sand	3	0	0 - 3	6.00
81	Gravel	22	0	[a]0 -22	.04
82	.....do	3	6	2½- 6	.00
83	.....do	2	0	2 - 5	.00
84	.....do	6	0	2 - 8	9.00
85	Gravel (bar)	3	0	1 - 4	.00
86	Gravel	6	0	2½- 8½	9.00
87	.....do	4	0	5 - 9	3.00
88	.....do	6	0	1 - 7	.00
89	.....do	8	0	2½-10½	.00
90	.....do	6	0	1½- 7½	.00
91	.....do	4	0	2 - 6	.00
92	.....do	5	6	3½- 9	.00
93	.....do	5	0	6 -11	.00
94	.....do	6	0	9 -15	.00
95	.....do	6	0	2 - 8	.00
96	.....do	3	0	1 - 4	.00
97	.....do		3	[a]15	5.00
98	.....do		3	[a]6	3.00
99	Coarse quicksand, slightly gravelly	3	0	1 - 4	33.50
	Average for all localities				5.10

[a] On or extending to bedrock

[b] Assay return.

Because of their paucity in gold and their excess in sand, especially in heavy sand from which the gold can not be separated by normal placer methods, and because of their consolidated condition, which in some localities necessitates crushing, the deposits are not regarded as workable or as having commercial value.

The facts that the operations of the Shoshoni Gold Dredging Co.'s dredge in the Neble area proved a failure and that, except at the west end, the ground has been prospected only surficially on the recent river bars make it very doubtful whether even this area contains workable deposits. The attention of those who may contemplate installing a dredge here should be called to the fact that in other placer fields, as at Oroville, Cal., where plants completely equipped with all modern appliances are in operation, similar deposits, though high in gold, are considered nonworkable, owing to their large content of fine heavy sand.

○

R D Crawford

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
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BULLETIN 580—H

CARNOTITE NEAR MAUCH CHUNK PENNSYLVANIA

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BY

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1914

DEPARTMENT OF THE INTERIOR
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WASHINGTON
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1914

CARNOTITE NEAR MAUCH CHUNK, PENNSYLVANIA.

By Edgar T. Wherry.

INTRODUCTION.

The occurrence of carnotite near Mauch Chunk, Carbon County, Pa., was noted by the writer in 1908 [1] and was fully described by him four years later.[2] The recent increase of interest in carnotite as a source of radium has made it seem worth while to prepare this additional note, placing on record the results of further chemical examination of the mineral and discussing the possible commercial value of the deposit, a point which was not touched on in the previous articles.

LOCATION.

The exact locality is the eastern termination of Mount Pisgah, about three-quarters of a mile north of the town of Mauch Chunk. The Central Railroad of New Jersey swings around the end of this ridge near the river level. About 100 feet higher up the slope is the highway from Mauch Chunk to Nesquehoning, Lansford, and Tamaqua. Just inside of this is an electric railroad line, to make place for which it has been necessary to cut a shelf about 2,000 feet long into the mountain side, the cut forming a rock wall that is 30 feet high at the east end and that gradually decreases in height toward the west. It is on this rock wall that the carnotite appears as an irregularly distributed but prominent yellow stain.

HISTORY.

The presence of a uranium mineral at this locality was noted as early as 1874,[3] but it was identified as autunite, the absence of phosphorus and the presence of vanadium escaping notice. Mr. John Eyerman, of Easton, Pa., informs the writer that the New York World in September, 1886, contained an article on the discovery of "metallic uranium" at Mauch Chunk, and that specimens obtained by him at that time showed a yellow coating, but that the specimens were not examined chemically. Thus twice was the opportunity lost to discover the mineral which in 1899, after an examination of specimens from Colorado, was described as carnotite.[1] The true nature of the Mauch Chunk material was discovered by the writer in 1908, when it was regarded as of no more than scientific interest, but inasmuch as material containing as little as 1 per cent of uranium oxide now finds a ready market for the preparation of radium salts, this deposit may prove to be worth prospecting, for it certainly contains some material of this grade, although the quantity apparently is small.

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[1] Science, new ser., vol. 29, p. 751, 1909.

[2] Am. Jour. Sci., 4th ser., vol. 33, pp. 574–580, 1912.

[3] Genth, F. A., Second Pennsylvania Geol. Survey, Rept. B, p. 144, 1874.

GEOLOGY.

The carnotite occurs in a 40-foot layer of coarse-grained conglomerate lying near the base of the Pottsville formation (Pennsylvanian) and just above the red Mauch Chunk shale (Mississippian). The strata dip 30°–60° S., into the mountain, and as the road follows the strike, the same bed is exposed throughout the cut. The rock consists of a rudely stratified mass of well-rounded pebbles, chiefly of white quartz, but in part of gneiss, crystalline limestone, and serpentine, averaging about 1 inch in diameter, though a few attain 6 inches. There are also lenses of dark-gray shale which show, under the microscope, in the midst of kaolin and quartz fragments, scattered grains of dark silicates and iron oxides.[2] These shale lenses are irregular in size and distribution, but one 4 feet long and 8 inches thick was noted. The cement of the conglomerate is in most places silica, the rock being a very hard quartzite, but here and there calcite takes the place of quartz. In the uptilting of the strata there has been considerable slipping of the beds on one another, as shown by slickensides on many of the surfaces.

The carnotite is thoroughly but unevenly distributed throughout the conglomerate. In the harder quartzitic variety it fills the few openings there may be, especially cracks in the pebbles themselves, and spreads over some of the slickensided surfaces; but by far the greater part of it appears as a replacement of the calcareous cement of certain portions of the conglomerate. These bodies formed by replacement are extremely irregular in size and shape, but most of them are only a few inches in diameter, although one near the east end of the cut is more than 10 feet wide. How far into the mountain these pockets extend it is impossible to say, but as the carnotite has evidently been deposited by the circulating surface waters—in fact, it can be seen in course of deposition where streams trickle out of cracks at the present time—it probably does not extend below the ground-water level and may be restricted to a very shallow zone.

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[1] Friedel, C., and Cumenge, E., Compt. Rend., vol. 128, p. 532, 1899.

[2] An unintentional misstatement in the writer's previous paper (p. 578) may be corrected here. It was stated that the shales "do not owe their color to carbon * * * but * * * chiefly to the presence of hornblende," etc. This should read: "They do not owe their color entirely to carbon," for an actual test shows the presence of considerable carbonaceous matter.

COMPOSITION OF THE CARNOTITE.

In the previous description of the material only an incomplete chemical analysis was given, for its impurity was so evident that it seemed a waste of time to do more than establish its general nature. After the appearance of the article, however, Dr. W. F. Hillebrand, of the Bureau of Standards, informed the writer that he had discovered a nearly pure calcio-carnotite [1] among specimens from Colorado, and suggested that if possible a redetermination of the potassium and calcium be made in the Pennsylvania material, so as to fix more certainly its position in the series.

A sample was accordingly separated from the gangue as carefully as possible and these elements determined, potassium by the chloroplatinate method and calcium as the oxalate. At the time it seemed worth while to check the values for uranium and vanadium, and since these had previously been determined volumetrically they were this time separated by the nitric acid evaporation method and weighed as oxides. As before, Mr. J. S. Long, of the department of chemistry of Lehigh University, assisted in the work, and thanks are here extended to him. The results of the analyses follow:

Analyses of carnotite from Mauch Chunk, Pa.

	1	2	3	4	5	Mol. No.
V_2O_5	7.2	21.1	9.80	21.73	21.34	1
UO_3	23.8	69.8	31.11	68.99	67.64	2
K_2O	(1.6)	4.7	3.55	7.86	11.02	1
CaO	1.5	4.4	.64	1.42	....	....
H_2O	10.5	....	7.13	....	....	....
Fe_2O_3	6.1	....	17.68	....	....	....
Insoluble	49.3	....	29.62	....	....	....
	100.0	100.0	99.53	100.00	100.00	....

1. Previous analysis; K_2O by difference.
2. Same, recalculated after deducting insoluble matter, water, and Fe_2O_3.
3. New analysis.
4. Same, recalculated as above.
5. Theoretic composition of potassio-carnotite on water-free basis.

Although here, as before, the admixture of silica, limonite, etc., in the material analyzed renders its exact nature somewhat doubtful, the uranium and vanadium oxides approach the 2:1 ratio characteristic of the autunite group. The relative amounts of potassium and calcium evidently vary from one specimen to another at this locality, but the presence of a carnotite high in potassium is now established.

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[1] In explanation of the nomenclature here used it may be pointed out that calcio-carnotite has now received a separate name, after the locality in Turkestan, Russia, where it occurs; this name is tjuyamunit in German, or, as it should be transliterated into English (rules of the Royal Society, the American Chemical Society, etc.), tyuyamunite. It is questionable, however, whether the introduction of such unnecessary new names into mineralogy is desirable. The writer favors applying the term carnotite to the isomorphous series as a whole and using potassio-carnotite and calcio-carnotite to describe the end members.

ORIGIN OF THE DEPOSIT.

The question how the mineral was formed can be readily answered. It evidently is simply a precipitate from the ground water and can be seen in the process of formation where water trickles out through cracks in the rocks. The real problem concerns the source of the uranium and vanadium dissolved in the water, for the region is notably free from all phenomena of igneous activity and deep-seated veins. The problem, moreover, is not merely of local significance nor limited to these metals; it is a part of the greater problem of the origin of the whole group of syngenetic sedimentary deposits, of copper shales, bedded iron and manganese ores, and other metalliferous strata, and the results obtained in the study of one phase of the problem may apply more or less to many others

If carnotite had been known when all strata were thought to be of marine origin, it would no doubt have been assumed that uranium and vanadium have been precipitated from the sea water, in which, like gold, they are of course present in extreme dilution; but now that the importance of continental deposition is recognized the matter becomes simpler. It is no longer necessary to assume concentration from almost infinitely dilute solutions. If these metals occur in the earlier rocks surrounding a given basin of continental deposition, they may become concentrated in the sediments in two ways: If the climate is such that decomposition exceeds disintegration, they may be dissolved by the rain water, carried down by the rivers, and, if these flow into lakes without outlet, become concentrated to such an extent as to be precipitated. If, on the other hand, the climate is so dry that disintegration is in excess of decomposition, mechanical transportation of the various minerals will take place, and those containing the heavy metals will be concentrated more or less completely into "black sand" lenses, because of their high specific gravities compared with that of quartz, which, as a rule, will make up the bulk of the sediment.

Mr. Frank L. Hess, in a recent paper on the origin of the western carnotite deposits, read before the Geological Society of Washington, has applied the first of these explanations to those deposits; but, as pointed out in the writer's previous paper, the second is the only one which seems applicable to the Mauch Chunk occurrence. Uranium-bearing minerals are common in pegmatites and vanadium-bearing dark silicates in gneisses throughout the pre-Cambrian and early Paleozoic crystalline rocks surrounding this region, and the climate of late Mississippian time is believed to have been decidedly dry, so that everything would seem to favor the operation of the process suggested by the second explanation.

COMMERCIAL VALUE OF THE DEPOSIT.

Present knowledge of the deposit is insufficient to warrant any statement as to its workability. The total area covered by the carnotite-bearing lenses is more than 50 square feet. As the rock weighs about 160 pounds to the cubic foot, every foot of its extent back from the rock wall would represent 4 tons. Analysis of a small specimen gave 4.4 per cent of uranium oxide, but this was a rich sample and it is doubtful whether much of the material runs over 1 per cent. However, as the cost of shipping the ore to consumers would be far less than that for the Colorado deposits, a profit of $25 a ton could be expected even on 1 per cent ore, and conservative prospecting of the deposit is to be recommended.

O

R A Crawford

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 580—I

LODE DEPOSITS
OF THE
ALLEGHANY DISTRICT, CALIFORNIA

BY

HENRY G. FERGUSON

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CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1913, PART I—I

WASHINGTON
GOVERNMENT PRINTING OFFICE
1914

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UNITED STATES GEOLOGICAL SURVEY
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LODE DEPOSITS OF THE ALLEGHANY DISTRICT, CALIFORNIA.

By Henry G. Ferguson.

TOPOGRAPHY AND LOCATION.

The mines of the Alleghany district, in the southwestern part of Sierra County, Cal. (fig. 47), are of interest not only on account of the extreme richness of the ore, some of which may contain as much as $100,000 a ton in gold, the apparently capricious distribution of the small shoots in which the high-grade ore is found, and the abruptness of the transition from these shoots to nearly barren quartz, but also because of the problems they offer in the study of vein formation. The mines visited by the writer are all within a short distance of the small towns of Alleghany and Forest. The northern boundary of the Colfax quadrangle, within which the district lies, is about a mile north of Forest. The region has the topography that characterizes the central portion of the Sierra, being made up of gently rolling interstream areas cut by deep and sharp river canyons. The canyons of Middle Fork of Yuba River and Kanaka Creek cross the southern and central portions of the Alleghany district. The Middle Fork canyon has an average depth of about 1,500 feet, but Kanaka Creek canyon is somewhat shallower. The northern part of the area is drained by the headwaters of Oregon Creek. The highest point, a little over 5,400 feet in altitude, is about a mile northwest of Forest. Between Forest and Alleghany the lava-covered interstream region has a width of about 2 miles, and south of the Middle Fork of the Yuba is another broad, flat upland area. Between Kanaka Creek and the Middle Fork, however, the ridge is narrow, reaching its greatest width, about a mile, above Chips Flat.

The district lies within the Tahoe National Forest, but the more accessible portions, although once heavily timbered, have been almost completely denuded. Difficulty of access has been a serious handicap to the mining industry. Nevada City, the terminus of the

Nevada County Narrow Gage Railroad and the nearest railroad station, is 25 miles distant in an air line but about 40 miles by stage road. Up to the present time the district has been almost completely isolated during the winter, and all supplies have been of necessity brought in before November. Even in summer the roads are often passable only with difficulty, and the freight rate from Nevada City varies with the condition of the roads, the minimum being $20 a ton. In May, 1913, a new road was being built to follow the canyons of Kanaka Creek and Middle Fork of Yuba River instead of crossing

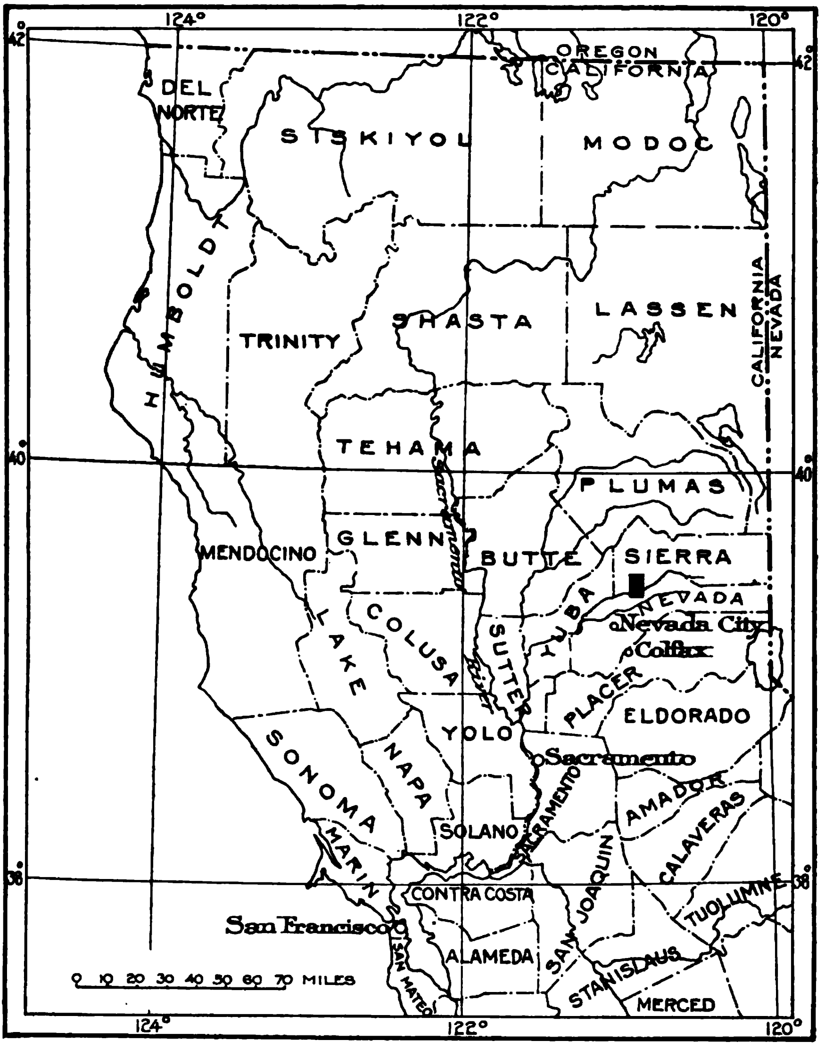

FIGURE 47.—Map of northern California, showing the location of the Alleghany district.

the ridges. This road will be passable for the greater part of the winter.

The district is reached by daily stage from Nevada City to Mountain House, where there is connection with another stage line for Alleghany. From June to September an automobile stage reduces the time of transit between Nevada City and Alleghany from 14 to 6 hours.

FIELD WORK AND ACKNOWLEDGMENTS.

The writer spent two weeks in the district in May, 1913, and made short visits to the principal mines then in operation. As the areal geology and the placer deposits have already been fully described by Lindgren, the writer confined his attention almost entirely to the lode mines. He is greatly indebted to all the mining men of the district, particularly to Messrs. A. B. Foote, R. H. Bedford, A. B. Hall, G. O. Scarfe, and W. B. Pierson, for their courtesy, hospitality, and many helpful suggestions. Mr. D. F. Hewett, of the U. S. Geological Survey, who visited the district in 1909, kindly placed his notes and specimens at the writer's disposal.

PREVIOUS DESCRIPTIONS.

Lindgren,[1] in the Colfax folio, has given an excellent description of the general geology of the region, together with a short note on the veins of this district. Turner[2] has discussed the geology of the Sierra Nevada as a whole and has given petrographic descriptions of rocks in the Downieville quadrangle, a short distance to the north. In his comprehensive work on the gravels of the Sierra Nevada Lindgren[3] has summarized the general geology and described the auriferous gravels of the vicinity. That report also contains a list of the more important publications relating to the Tertiary gravels.[4] The only paper dealing directly with the lodes of the Alleghany district is one by A. H. Martin,[5] which gives brief descriptions of the mines in operation in 1909. Another short account of mining in the district has appeared more recently.[6]

GEOLOGY.

The geologic map (fig. 48) of the region surrounding the Alleghany district is taken, with a few minor changes, from that published in the Colfax folio.

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[1] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Colfax folio (No. 66), 1900.

[2] Turner, H. W., U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, pp. 521–762, 1896.

[3] U. S. Geol. Survey Prof. Paper 73, 1911.

[4] Idem, p. 12.

[5] Martin, A. H., Alleghany mining district, Cal.: Min. World, vol. 31, p. 589, 1909.

[6] Special correspondence, Allegheny, Cal.: Min. and Sci. Press, July 5, 1913, pp. 22–23.

In the northeastern and southwestern parts of the area are the Carboniferous clay slates of the Calaveras group, represented by the Blue Canyon and Cape Horn formations, respectively, of that group. Separating these is a broad belt composed of gabbro, schistose amphibolite, and serpentine, which are considered by Lindgren[1] to be intrusive into the sedimentary series. Transitions occur between the gabbro and the amphibolite, and the amphibolite appears to have been derived from the gabbro by simple pressure.

Serpentine outcrops as bands bordering the amphibolite area and as strips within the amphibolite parallel to its schistosity. In all probability the serpentine is derived from a peridotite which was intruded into the original gabbro and between the gabbro and the sediments.

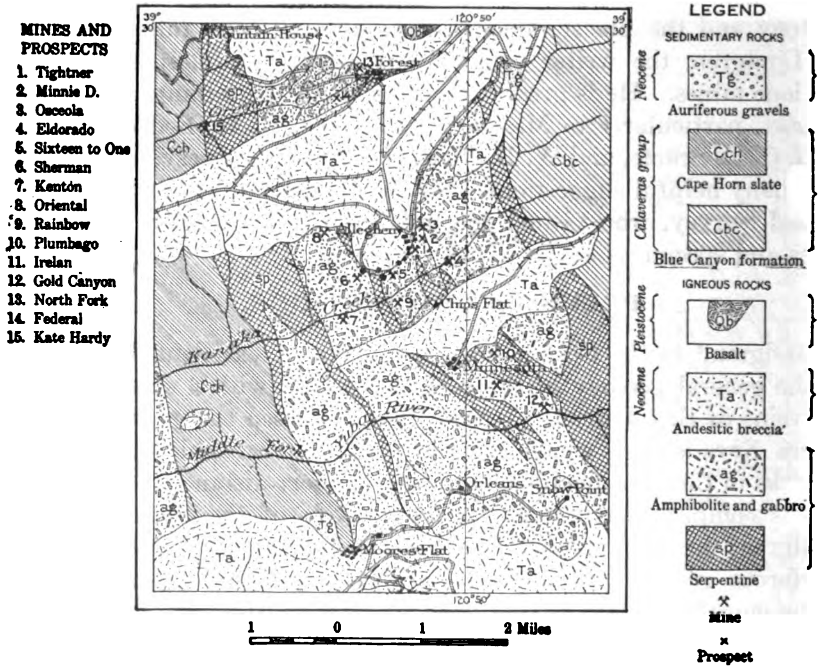

FIGURE 48.—Geologic map of the Alleghany district, Cal., and vicinity. Adapted from U. S. Geol. Survey Geol. Atlas, Colfax folio (No. 66), 1900.

Throughout the Sierra Nevada there are great masses of silicic igneous rocks—granite, granite porphyries, quartz monzonites, and granodiorites, of which the last are most prominent. The period of ore deposition closely followed the intrusion of these rocks. At only one locality in the Alleghany district, however, does a silicic rock occur near a vein. This is at the Oriental mine, where the veins, for a short distance, follow the borders of a small mass of much-altered microcline granite. A small area of granite, about 5 miles southwest of Alleghany, is shown on the geologic map accompanying the Colfax folio, and 5 miles east of the town is the western boundary of a great mass of soda granite which extends northward from the South Fork of the Yuba to the North Fork, in the southern part of the adjoining Downieville quadrangle. The nearest outcrop of the large granodiorite mass of the Nevada City and Grass Valley region is close to the Federal Loan mine, about 22 miles southwest of Alleghany. A small area of granite porphyry lies along the northern border of the Colfax quadrangle, about 5 miles northwest of Alleghany.

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[1] U. S. Geol. Survey Geol. Atlas, Colfax folio (No. 66), p. 3, 1900.

The "Superjacent series" as represented in this region consists of the Neocene auriferous gravels overlain by andesitic breccia. These deposits cover the upland areas between Forest and Alleghany, between Chips Flat and the Plumbago mine, and south of the Middle Fork of the Yuba. The gravels have been so fully described by Lindgren[1] that it is not necessary to go into detail concerning them here. The Tertiary channel of the Middle Fork paralleled the present course of the river about a mile to the south, and in it were accumulated the placer deposits of Snow Point, Orleans, and Moores Flat. A tributary stream flowed southward from Forest, through Alleghany, Chips Flat, and Minnesota. This stream and its tributaries crossed the outcrops of many of the rich quartz veins of the district, and much of the gravel it laid down was extraordinarily rich. Several of the quartz mines of the region were discovered in drift mining beneath the capping of andesitic breccia.

According to Lindgren[2] no flows of massive andesite are present in the Alleghany area, the ejected material having flowed down the old river valleys as volcanic mud mixed with water. This mud later consolidated to a hard, compact mass.

A small body of basalt of early Pleistocene age caps the andesitic breccia of Table Mountain, about a mile north of Forest. The rock is of normal character, black, and fine grained and generally contains small crystals of olivine. The bedrock tunnel of the Bald Mountain Extension Co. crosses a dike of basalt which cuts the serpentine and the overlying Neocene masses.[3] An interesting occurrence of basalt of a similar type associated with andesitic fragments was observed on the third level of the Plumbago mine. The andesitic fragments are numerous and fairly well rounded. With them are a number of small angular fragments of vein quartz. The matrix is made up of fragments of augite and feldspar and small grains of vein quartz. The basalt is clearly later than this andesitic breccia and cuts it in a rather irregular dike. The breccia and the dike follow the course of the vein for more than 200 feet on the dip and not quite so far on the strike. Presumably this is the neck of a Neocene volcano, from which came a portion of the andesitic breccia that caps the present divide. The basalt dike corresponds petrographically to the Pleistocene basalt described by Lindgren.

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[1] U. S. Geol. Survey Prof. Paper 73, pp. 133–159, 1911.

[2] U. S. Geol. Survey Geol. Atlas, Colfax folio (No. 66), p. 6, 1900; U. S. Geol. Survey Prof. Paper 73, p. 137, 1911.

[3] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Colfax folio (No. 66), p. 7, 1900.

In the more recent gravels of the shifting bars of Kanaka Creek and Middle Fork of Yuba River the gold content has been reconcentrated from the Neocene gravels and furnished extremely rich placers in the early days of mining.

The following summary of the geology of the district is condensed from Lindgren's description[1] in the Colfax folio. The oldest rocks of the region are of Carboniferous age and belong to the Calaveras group. They have the appearance of one conformable series, the thickness of which it is difficult if not impossible to determine with accuracy. They should perhaps be regarded as thrown into many sharply compressed folds, nearly vertical or sharply overturned eastward. After the deposition of the Triassic and Jurassic beds upon the upturned strata of the Calaveras group came a period of mountain building, during which the later beds were folded against the Carboniferous land masses. Probably during latest Jurassic or earliest Cretaceous time the great eruptions of igneous rock occurred. The general sequence of these rocks has not been fully ascertained. The main granitic masses are, in general, more recent than the greenstones and serpentines, and in a given area of granular rocks the darker modifications are nearly always older than the lighter-colored silicic facies. The intrusions were followed by the principal period of ore deposition.

The later history of the region[2] includes the building of a high mountain range and its reduction to a region of very gentle topography. In late Cretaceous time came the beginning of the organic disturbances and faulting which have formed the present Sierra Nevada. A long period of erosion followed, and in Neocene time began the accumulation of the auriferous gravels. Volcanic activity beginning in the Neocene and continuing at intervals into the Pleistocene has left the breccias and lavas which cover the interstream areas.

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[1] Op. cit., pp. 4-6.

[2] Lindgren, Waldemar, U. S. Geol. Survey Prof. Paper 73, p. 44, 1911.

HISTORY AND PRODUCTION.

The Alleghany district was one of the early discoveries in California gold mining. At first the rich river bars absorbed the attention of the miners. After the exhaustion of the bars, work was largely confined to the Neocene gravels, and hydraulic mining, followed by drift mining, was at first the principal occupation of the camps. During this period lode mining had been carried on in a desultory way and occasionally masses of rich ore were taken from the veins. The Plumbago, at least, has been worked at intervals since some time before 1860, and several other mines for comparable periods. The history of the camp, as an important producer, begins, however, in 1907 with the rediscovery of the Tightner vein by H. L. Johnson. Apex litigation greatly reduced the output in 1909, but production increased the next year, and in 1912 the shoots of rich ore in the Tightner and other mines gave a production more than double that of any preceding year. Probably the output for 1913 exceeded even that of 1912.

It is impossible to obtain any figures as to the output from the quartz veins of the district, distinct from the placers before 1908. Lindgren[1] estimates that, out of a total production of $150,000,000 up to 1909, the yield from quartz mines in the entire Colfax quadrangle has not exceeded $10,000,000. Probably half of this was derived from the mines in the vicinity of Alleghany. The following table gives the production of the lode mines of the district since 1908:

Deep-mine production of the Alleghany district, Cal., 1908–1912.

[From Mineral Resources of the United States.]

	Ore treated (tons).	Gold.	Silver (ounces).	Producing mines.
1908	13,626	[a] $173,866	(a)	3
1909	1,514	[a] 41,379	(a)	8
1910	7,485	110,554	976	3
1911	10,350	113,675	1,121	8
1912	18,389	[a] 293,561	(a)	5

[a] Silver production not given separately.

ORE DEPOSITS.

GENERAL FEATURES.

All the lodes visited are well-marked fissure veins, which are confined almost exclusively to the amphibolites. The Kate Hardy vein cuts the Cape Horn slate near the serpentine contact and the Oriental veins follow the contact between amphibolite and microcline granite for a short distance, but these are the only exceptions. Where the veins pass from the amphibolite into the serpentine they split into small stringers, which die out within short distances. This is particularly well seen in the Gold Canyon and Oriental mines. The amphibolite on the walls of the veins is usually so intensely crushed as to be altered to a chloritic or talose schist somewhat resembling serpentine. This has led to the belief that all the veins lie along the contacts of serpentine and amphibolite, an idea which has caused a certain amount of barren prospecting. The veins are, for the most part, very persistent in the amphibolite, though they vary greatly in width. Where the quartz pinches out there is generally a well-defined wall, with more or less gouge, which can easily be followed to the point where the quartz reappears. Exceptionally the quartz may attain a width of 30 feet in the so-called swells.

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[1] U. S. Geol. Survey Prof. Paper 73, p. 133, 1911.

Movement along the veins has been very pronounced, and for the most part the veins, together with a certain amount of crushed country rock, lie between smooth walls. At certain places these walls leave the lode and pass as slips into the country rock, diverging at small angles from the strike and dip of the vein. At such places the lode for a short distance is without a well-defined footwall or hanging wall. It appears that the stress which produced the slickensided walls was exerted in directions that in homogeneous material would have resulted in fissures oblique to the vein. The angle of obliquity, however, was so small that the movement for considerable distances took place along the vein. The grooving and slickensiding on the walls of many of the lodes indicate that the last movement along these surfaces was more nearly horizontal than vertical.

Transverse faults are exceptional. In places, as on the second level of the Gold Canyon mine, the quartz is displaced a few feet by a movement which was earlier than the last movement parallel to the vein, as the present vein walls are not disturbed. The only large transverse fault is that which cuts the Tightner vein. Between the upper and lower workings that vein is displaced by a fault zone, consisting of a group of closely spaced nearly vertical parallel fissures which intersect the vein at a small angle and produce a vertical displacement of 100 feet and an estimated horizontal offset of 300 feet. Probably movement parallel to the vein was in part later than this faulting.

The strike of the veins is almost without exception northwesterly and varies from nearly north to about N. 60° W. A few veins, such as the Oriental, have an east-west strike. The dips of all the veins are low, 40° to 60° being average dips throughout the district. Single veins, however, show great variation, the difference at different levels being not uncommonly as much as 30°.

MINERALOGY.

GANGUE MINERALS.

Quartz is the principal mineral of the veins and is the only host of the rich sulphides and free gold. Lenticular masses of a dark quartz occur in the amphibolite and slates. Except for rare specks of pyrite these quartz lenses contain no metallic minerals and, so far as known, are not gold bearing. In the vein quartz two generations can be distinguished. The quartz of the first generation forms the bulk of the veins and is coarsely crystalline and in places vuggy. The largest vug seen had a maximum diameter of 2 or 3 feet, but most of these cavities do not exceed a few inches. Prismatic crystals, from a fraction of an inch to 6 inches in length, line the vugs. In the uncrushed massive quartz the microscope shows interlocking grains with few definite crystal boundaries. The quartz, seen in the hand specimen, is milky white in color, rather than transparent. By the aid of the microscope this color is seen to be due to reflection from the surfaces of innumerable minute cavities. These are not greater than 0.01 millimeter in diameter and usually much less, but are so closely spaced that thin sections of the quartz have a decidedly cloudy appearance under the microscope. Two kinds of these little bubble-like cavities are present. Those of one kind, where any definite relation can be observed, are arranged in rather shadowy lines, parallel to the prism and pyramid faces of the quartz crystals. A narrow border of clear quartz generally surrounds the cloudy area. These cavities appear to be filled with a liquid, and where they are particularly well developed, as in the large crystals projecting into the vugs, small moving gas bubbles may be seen under the highest power of the microscope. These bubbles move upward as the stage is rotated, but with a slow and rather uncertain movement as if inclosed in a viscous liquid. Most of the liquid-filled cavities are irregular in outline, but a few appear to be fairly definite negative crystals. The cavities of the other kind follow rather more definite lines and tend to lie with their long axes parallel. Their outlines are irregular and the moving bubbles were never observed in them. In many places the lines of these cavities cross from one quartz grain to another without change of direction. It would seem that the cavities of the first kind were formed contemporaneously with the crystallization of the quartz, and that those in which the linear arrangement is marked are the result of shearing and subsequent healing of the already formed grains. As a rule the larger quartz grains do not show the cloudy or wavy extinction attributable to strain, but a few of the smaller grains in the minute veinlets which cross the arsenopyrite crystals show a distinctly wavy extinction.

Many of the larger grains have an indefiniteness of total extinction which is due to reflected light from the surfaces of the minute cavities. Rarely the larger grains show the peculiar "flamboyant" extinction sometimes seen in vein quartz.

The later quartz is an inconspicuous feature of the veins as a whole. Many of the crystals of the vugs are coated with minute transparent quartz crystals. Rarely, as in specimens obtained at the Irelan mine, the large crystals of the older quartz have been coated with successive layers of chalcedonic and finely crystalline quartz until their outlines are almost lost. In many places minute veinlets of clear quartz cross the milk-white quartz of the veins. These are generally not more than a millimeter wide. Under the microscope they are seen to be composed of minute slender crystals, which, in polarized light, give a feathery effect.

Albite is rare in the veins but where present it forms fairly large crystals close to the walls. Most commonly it is in the small stringers branching out into the schists rather than in the larger veins.

Calcite occurs as a replacement mineral in the wall rock rather than in the veins, as much of the wall rock gives a slight effervescence with cold dilute hydrochloric acid. The great mass of the carbonate mineral present is, however, a dolomite. In places the carbonate has evidently migrated from the altered wall rock into the vein as a replacement of the older quartz. It also forms small veinlets in the quartz and rarely between the quartz and arsenopyrite, or crosses the larger arsenopyrite crystals in veinlets less than 0.1 millimeter wide.

Mariposite, a vivid-green chromium-bearing micaceous mineral, is associated with ferriferous dolomite in the altered wall rock. This dolomite-mariposite aggregate, although largely composed of calcite, has a viridian green color due to this disseminated mariposite and is lined with small white veins of later calcite. The brilliant color of this mixture makes it a prominent feature of the veins and has earned for it the local name of "blue jay." Like the dolomite, the mariposite occurs in a few localities as a replacement of the quartz but nowhere far from the altered wall. Under the microscope the "blue jay" is seen to consist largely of the carbonate with shreds of the green mariposite scattered through it in irregular lines. The mariposite, as seen in thin section, is bright green and is faintly pleochroic. It resembles sericite, save that owing to its greater absorption of light, the polarization colors are far less brilliant. Exceptionally the green color is very faint, so that the mineral is hardly distinguishable from sericite. In the veins of the Mother Lode region mariposite is generally found where serpentine is the wall rock. In the Alleghany district, however, the mineral occurs as a replacement of the talcose or chloritic amphibolite.

Sericite occurs in minute veinlets in the quartz, especially in the crushed portion, and also as partial replacements of quartz grains. It is probably present to some extent as an hydrothermal alteration product in the wall rock, but as the amphibolite schist is in part altered to talc along the walls of the veins and as none of the altered material collected appeared to be of sufficient purity to justify microchemical tests, it is uncertain how far the sericite has replaced the wall rock. In specimens of microcline granite collected close to the Oriental vein no sericitization of the feldspars is apparent under the microscope.

Dolomite of a second generation and lime-bearing siderite are among the last minerals formed. In specimens from the Rainbow and Minnie D. mines dolomite appears as bladed semicircular crystals about a centimeter in diameter grown upon the quartz of the later generation, and in specimens from the Minnie D. and Twenty One reddish siderite occurs in a similar association.

METALLIC MINERALS.

Arsenopyrite is the most important sulphide in the veins, both from its gold content and as an indicator of the shoots of rich ore. The mineral is found both in the veins and in the altered wall rock, but its mode of occurrence is somewhat different in the two situations. In the veins it occurs in large bladed crystals and irregular crystalline masses much broken and veined by quartz, and more rarely in minute distinct crystals of octahedral habit. Even in the most completely shattered portions of the larger individuals crystal faces can be found, and in a few specimens crystals 4 to 5 centimeters in length and 5 millimeters in width are distinct and sharp, though cut by minute veinlets of quartz or gold and slightly faulted across, with displacements of a millimeter or less. Where there has been later crushing in the quartz, however, the arsenopyrite is smeared out along the line of movement in dusty bands that give one form of the banded quartz which is regarded as a favorable indication. In some places cleavage fragments of original crystals and more rarely minute perfect crystals of octahedral habit are discernible under the microscope. These crystals are believed to be the result of recrystallization of the dustlike arsenopyrite fragments in the zones of crushing rather than of a second accession of material. In certain localities, particularly in the Gold Canyon mine, much of the arsenopyrite in the quartz is massive crystalline, and these masses are rudely rectangular in outline and have sharp boundaries which suggest the complete replacement of fragments of the wall rock, or possibly fragments of large sulphide masses. In these occurrences, as well as in the crystals, the arsenopyrite is shattered and veined with quartz. In the wall rock, or as a partial replacement of fragments of the wall rock in the vein close to the walls, arsenopyrite has crystallized in minute slender prisms or less commonly as barely visible crystals of octahedral habit.

Coarse gold is a notable feature of the veins of the Alleghany district. So far as the writer is aware, the little bunches of exceptionally rich ore have been found only in the quartz and in close connection with the coarsely crystallized arsenopyrite (fig. 49). The gold occurs in the arsenopyrite chiefly as a replacement, but perhaps in part also in solid solution with the sulphide. It is to be noted, however, that the arsenopyrite of the near-by wall rock is almost barren, and that the fine crystalline arsenopyrite found in the veins at a distance from the shoots of high-grade ore carries comparatively small amounts of gold.

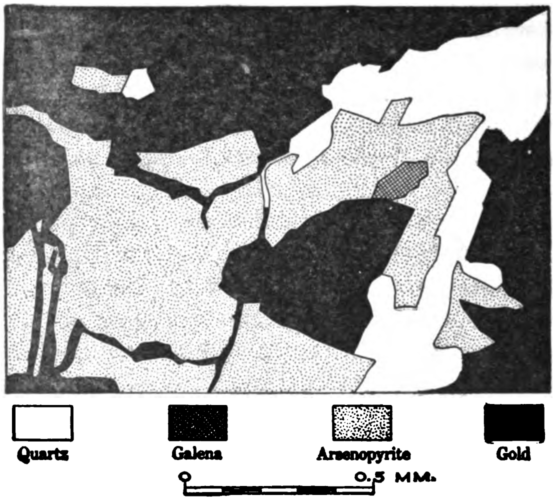

FIGURE 49.—Gold and galena in arsenopyrite. The small veinlets of gold crossing the arsenopyrite appear to be, in part at least, replacements of quartz.

D. F. Hewett made some assays on material from the German Bar mine which illustrate this point, and the following table is quoted from his notes:

Assays of material from German Bar mine.

	Gold.		Silver.		Total value.
	Ounces.	Value.	Ounces.	Value.	
1	0.41	$8.47	0.12	$0.06	$8.53
2	4.68	96.73	.47	.23	96.96
3	460.56	9,519.79	42.51	21.25	9,541.02

1. Quartz showing fine arsenopyrite and banding, from raise from lowest tunnel.
2. Concentrate from No. 1. 342 grams of No. 1 concentrate into 29 grams of No. 2 (11.8 into 1). Results show saving of 98 per cent of gold and 32 per cent of silver in operation.
3. Coarse arsenopyrite, not showing free gold. From lower tunnel.

In the rich arsenopyrite the visible gold may occur either as irregular replacements ranging in size from particles at the limit of microscopic observation to patches several millimeters across, as minute threadlike veinlets, or as replacements of the quartz veinlets that cross the arsenopyrite. At the borders of the broken crystal fragments the gold replaces both the quartz and the arsenopyrite (fig. 50). Away from the arsenopyrite the gold cuts the quartz in small irregular fissures, apparently involving but little replacement. In some of the rich ore from the Tightner mine small veinlets of gold cross the zones of broken quartz, but in many specimens the gold is itself polished and slickensided by later movement. The gold in the quartz at a distance from the arsenopyrite is usually associated with galena. A rare but fairly characteristic feature of the rich ores is the presence of gold in octahedral crystals on the quartz crystals of the smaller vugs. In a few of the specimens examined minute specks of a reddish spongy gold were seen upon the plates and crystals of light-yellow gold in the quartz. As the reddish spongy gold is clearly later than the greater part of the gold in the veins it may have been deposited by downward-flowing surface water.

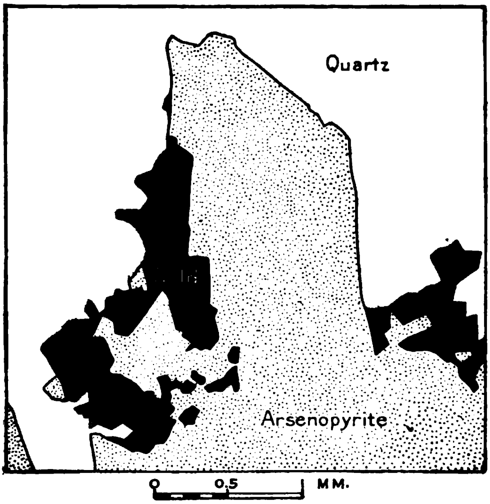

FIGURE 50.—Gold replacing quartz and arsenopyrite.

Galena is not an abundant constituent of the deposits, but is usually found in close association with the gold of the rich ore. Commonly it occurs as a replacement of quartz (fig. 51). There is usually a small nucleus of solid cleavable galena from a fraction of a millimeter to 2 or 3 millimeters in diameter, and from this radiate delicate needles, extremely narrow, and not exceeding 2 millimeters in length, similar to rutile

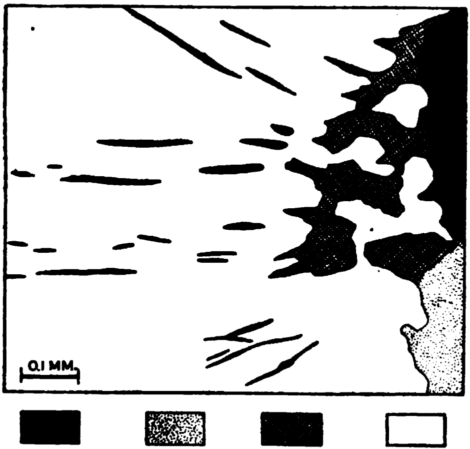

FIGURE 51.—Galena replacing quartz.

needles replacing quartz, but so closely spaced that the clusters resemble minute chestnut burrs. Examination of thin sections of galena in quartz shows that these minute rays in places cross different quartz crystals.

Dark-brown sphalerite, generally in very minute specks, can be seen in the vicinity of the galena in much of the quartz. It is far less abundant than the galena and was never seen in such close association with the gold.

Pyrite is found in several different associations. To some extent it replaces the quartz of the vein. In this situation it is generally associated with the other sulphides and is presumably of the same age as the galena. Rarely pyritohedrons are implanted on the faces of quartz crystals in the vugs. In the mariposite and dolomite replacement of the country rock pyrite is always present and is apparently slightly later than the intergrown mariposite and dolomite and contemporaneous with the later white carbonate which veins the green mass. Pyrite of a distinctly later generation and presumably deposited by circulating surface waters is found in small fissures and in layers of minute octahedral crystals, coating the later quartz. Marcasite has been reported in the same position, and specimens of a very minutely crystalline mineral that appeared to be marcasite were collected for examination in the office. On unpacking the material, however, it was found to have oxidized and lost its crystal outlines.

Tetrahedrite, carrying arsenic as well as antimony, is rare in the Alleghany district, but was noted in specimens from the Tightner, Plumbago, and Kate Hardy mines. In the Tightner it occurs in the same general neighborhood with the other sulphides and free gold, but most closely associated with the pyrite. Rarely small specks of tetrahedrite occur on the faces of crystals of pyrite. In other veins tetrahedrite was found only as small specks in the quartz.

Chalcopyrite was seen in most of the veins. In many places it occurs in isolated specks in the veins, and, although not found in the country rock, it is scattered throughout many of the veins in small irregular masses.

ORDER OF CRYSTALLIZATION.

The microscopic structure of the vein quartz and arsenopyrite shows that the arsenopyrite of the vein crystallized earlier than the quartz. As already explained, the arsenopyrite is seamed and fissured with minute quartz veinlets. (See fig. 52.) This quartz does not, as a rule, belong to a later period of mineralization but is of the same age as the quartz which makes up the body of the vein. This is well shown at the mouths of the little veinlets of quartz which intrude the arsenopyrite. Here the veinlets of quartz, for distances of several hundredths of a millimeter, are portions of the same large crystal which partly surrounds the arsenopyrite. Not only is the optical orientation the same, but the quartz in the veinlet has the same cloudy appearance, due to the presence of minute bubbles, as the quartz in the main mass of the vein, and there is no evidence of any boundary line between the portion of the quartz crystal in the main vein and the portion in the small veinlet. The distinctly later veinlets of quartz, which cross both the earlier quartz and the arsenopyrite, are invariably clear and free from bubbles. Moreover, angular fragments of arsenopyrite separated by distances of a fraction of a millimeter from the large crystal are found entirely inclosed in a single quartz individual. The reentrants of such fragments agree with the angles of the larger arsenopyrite mass and afford evidence of a character similar to that given by the quartz veinlets. It seems most natural to assume that the solution from which the quartz and arsenopyrite crystallized was essentially without motion at the time of the crystallization of the arsenopyrite and, for a short time at least, was sufficiently viscous to allow of small pieces of the wall rock being held without sinking. The arsenopyrite to some extent migrated into and replaced the wall rock but for the most part crystallized in the fissure about whatever nuclei were available, such as the walls themselves and small fragments

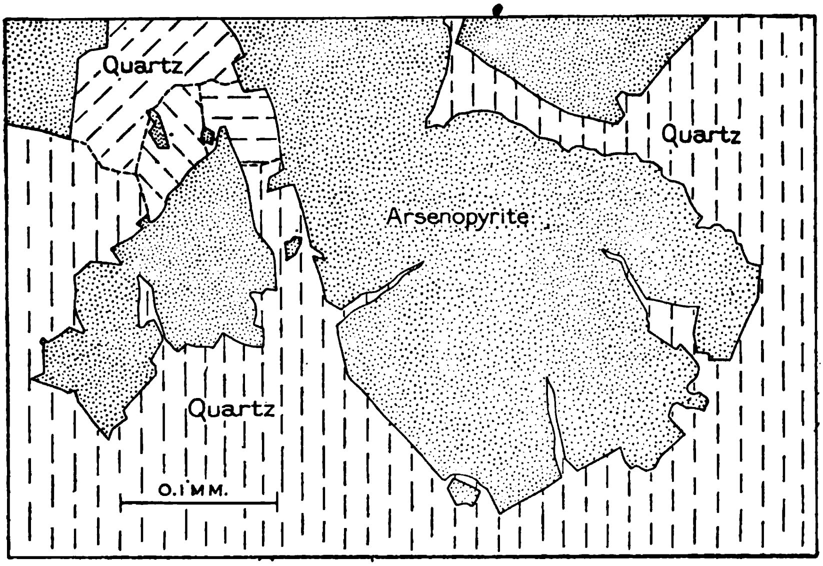

FIGURE 52.—Arsenopyrite veined by a single quartz crystal, seen by polarized light. The different quartz crystals are indicated by the directions of the broken lines.

and specks of the wall rock in the solution. It is supposed that after the crystallization of the arsenopyrite outside motion of some sort stirred the supersaturated quartz solution and caused it to fissure and drag the already crystallized arsenopyrite at the same time that a rapid crystallization of the quartz set in.

Vein formation of an essentially similar nature has been noted by Ransome[1] in the Silverton quadrangle, Colo., by Graton[2] in the auriferous quartz veins of the southern Appalachians, and by Hess[3] in the tin deposits of the Black Hills.

The formation of the dolomite and mariposite mixture in the altered wall rock was clearly later than the crystallization of the quartz, for all three of the members of this aggregate, mariposite, dolomite, and pyrite have been observed as replacements of the quartz. Possibly it is to be correlated with the introduction of the gold and sulphides.

After the crystallization of the quartz there was movement parallel to the walls which crushed the quartz along narrow bands, and in places the arsenopyrite crystals were comminuted and dragged out. This was followed by the introduction of the gold and galena and probably of the other sulphides also. The gold is clearly of later date than the crushing of the quartz, as minute threadlike veins of gold cross the crushed zones. It is probable that the gold is contemporaneous with the galena, as both occur in close association without replacement one by the other and both are younger than the quartz and arsenopyrite. Probably the other sulphides of the vein—pyrite (the earlier series), sphalerite, tetrahedrite, and chalcopyrite—belong to the same period.

It is not intended to imply that any great interval separated these different periods of mineral introduction. The evidence shows that they were distinct, but it is impossible to say whether they are to be considered as separated by intervals of minutes or of years.

Distinctly later action, separated from the earlier periods of vein formation by a long interval, is shown by the fine-grained chalcedonic quartz, the later carbonates and pyrite, and the rare small specks of reddish gold. These, it is thought probable, were deposited from generally downward-flowing atmospheric waters.

ORE SHOOTS.

The extreme localization of the gold is a feature of all the mines of the district and has led to their being referred to as "pocket mines." This is not a fair description, however, for a "pocket" in California miners' usage often refers to gold found outside of any well-marked veins. In the deposits of the Alleghany district, on the other hand, the rich ore is in the veins and in small but distinct ore shoots. The great mass of the quartz of the veins is of extremely low tenor. Much of it carries even less than $1 or $2 worth of gold to the ton, and this is largely in the sulphides. The concentrates from portions of the vein outside of the ore shoots carry $50 or less to the ton in gold and form only about 1 per cent by weight of the ore. In the small ore shoots, however, the ore may carry as much as $40 or $50 in gold to the pound, for the most part free gold. Some of these very rich masses have been found immediately adjacent to the nearly barren quartz; more commonly, however, the richest spots grade off into the vein quartz within distances of a few feet. The amount of rich ore in a single shoot may be from a few pounds to several tons. In the several mines different features of the veins are looked upon as indicators—in fact, the so-called indicators are nearly as numerous as the mines themselves. Among such guides are the presence of either more or less "blue jay" than usual, a "hard cabby hanging," rolls in the foot and hanging walls, sharp changes in dip or strike, banding of the quartz, and intersecting veinlets. The writer's conclusions in regard to genesis as given in the following paragraphs are based on a small amount of field work and hence are offered with some hesitation. The explanation presented may not be as fully supported as would be desirable, but it is at least in accord with the facts observed.

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[1] Ransome, F. L., U. S. Geol. Survey Bull. 182, p. 136, 1901.

[2] Graton, L. C., U. S. Geol. Survey Bull. 293, p. 72, 1906.

[3] Hess, F. L., U. S. Geol. Survey Bull. 380, p. 140, 1909.

The gold, as has already been shown, is distinctly later than the arsenopyrite, but the coarsely crystalline arsenopyrite carries gold visible with the microscope if not always to the unaided eye. Palmer and Bastin[1] have shown that arsenopyrite is an extremely effective precipitant of gold. Hence it appears reasonable to suppose that the later solutions traveling through the crushed quartz of the vein tended to deposit their gold content when they reached the arsenopyrite and to replace a portion of the arsenopyrite and the neighboring quartz. Also in the quartz near the arsenopyrite, though not in direct contact with it, gold and such sulphides as galena, tetrahedrite, and sphalerite were deposited in minute fissures or as replacements in the quartz. Where open spaces, such as vugs, afforded the opportunity, gold crystals were formed. The gold-bearing solutions were confined to the vein, for although arsenopyrite occurs in the country rock the arsenopyrite crystals in the vein alone carry free gold. Hence the formation of the ore shoots depends on two sets of conditions—those which determined the formation of masses of coarsely crystalline arsenopyrite in the veins and those which determined the paths followed by the later solutions, which carried the greater part of the gold. Of these conditions the first set seems to have been the more influential, for so far as the writer is aware all the coarse arsenopyrite found in the veins has a high gold content and almost invariably is closely associated with coarse gold. It may therefore be assumed that the gold-bearing solutions were fairly ubiquitous within the vein, and that the presence of the arsenopyrite to a great extent determined the ore shoots. (See fig. 53.)

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[1] Econ. Geology, vol. 7, pp. 140–170, 1913.

As has already been explained, it is believed that the arsenopyrite crystallized out from a still fluid quartz solution, in a manner comparable to the formation of the large tourmaline crystals along the walls of a pegmatite dike. The most favorable localities for the formation of these large arsenopyrite crystal masses would naturally be those portions of the veins where there was possible a maximum amount of circulation. This condition seems to have been met, in the Tightner and Rainbow mines at least, by the localization of the arsenopyrite along the edges of lenticular swellings in the veins. These enlargements themselves appear to be due to intersections with other veins. In the Plumbago and Oriental mines the general location of the small shoots of high grade has been assigned to intersections of transverse veins with the main vein. In the Tightner mine rich shoots have been found at two points on the lower level. Each of these shoots is near the north end of a marked enlargement in the vein and about 100 feet north of an intersecting vein on the hanging wall. The old stopes of the Rainbow appear to show a similar relation. It is supposed that the opening was wider at the junction of two channels, and, therefore, when movement in the solution ceased there was greater opportunity for differentiation here than elsewhere in the veins, and it was at favorable localities along the edges of these enlargements that the arsenopyrite crystallized. This original concentration of the arsenopyrite determined the locus of deposition of the gold carried up by later solutions.

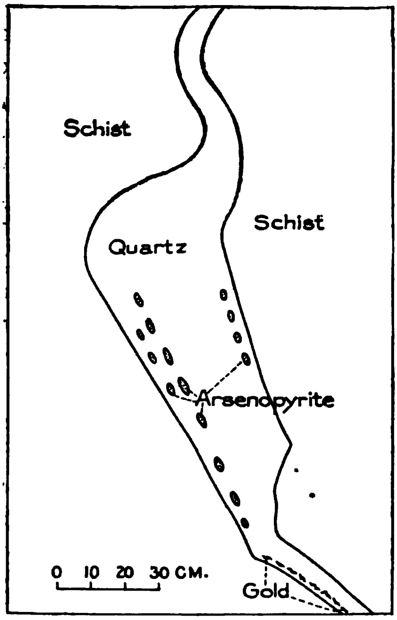

FIGURE 53.—Sketch of Gold Canyon vein, Alleghany district, Cal., showing occurrence of arsenopyrite and free gold.

If the explanation above offered is the correct one, it follows that most of the small ore shoots will be found near the circumferences of the lenticular swellings of the vein, and that these enlargements will in any one mine be found at similar distances from intersecting veins. The distances and directions will vary in different mines according to the magnitude and direction of the movements along the vein walls.

MINES.

TIGHTNER MINE (1).[1]

The Tightner vein, directly beneath the town of Alleghany, was rediscovered by H. L. Johnson in 1907. During the placer operations of the early years of the camp the vein had been cut in a bedrock tunnel, but no attention was then paid to it. The report that a very rich gravel had been found in the neighborhood of the vein led Mr. Johnson to reopen the bedrock tunnel and drift on the vein. He was rewarded by the discovery of a few tons of very rich ore on the first level and several smaller patches elsewhere in the upper workings. He is reported to have taken out more than $400,000 in gold. The present company began operations in 1911 and has developed the vein on the lower level, entered by a long tunnel at an elevation of 4,080 feet. The production under the present management has been about $600,000 to June, 1913. At the time of visit there was a 10-stamp mill on the property. Lately 10 stamps more have been added.

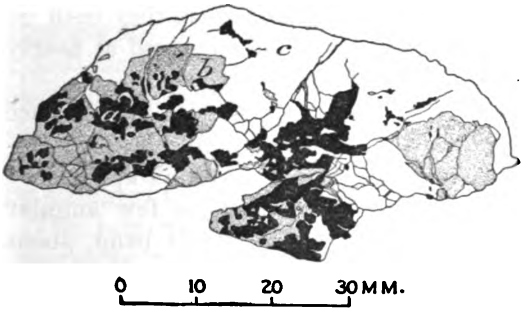

FIGURE 54.—Rich ore from Tightner mine, Alleghany district, Cal. From a photograph. *a*, Gold; *b*, arsenopyrite; *c*, quartz.

The wall rock of the vein is amphibolite schist, which is much altered near the vein. Where the movement has been most intense the rock has been altered to a talcose schist. Hydrothermal alteration is common but irregular. Masses of dolomite and mariposite are irregularly distributed along the walls, and in places there is silicification as well. The vein crosses the steeply dipping laminæ of the schist, but the schist is so sheared and altered near the walls that the difference in dip between the veins and the schist can only rarely be observed. On the first level the crosscut passed through a small band of serpentine about 75 feet from the vein. A small vein consisting of quartz, talc, and calcite crosses the serpentine.

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[1] Numbers refer to map, fig. 48.

The principal vein has been followed for about 1,800 feet. In two places the quartz pinched out but reappeared a short distance beyond. The maximum width is about 20 feet. The strike varies in different parts through an angle of about 45°, and the dip ranges from 30° to 55°. Between the upper and lower workings the vein is cut obliquely by a composite fault of about 100 feet vertical and 300 feet total horizontal displacement. Along the fault planes there is a small amount of crushed quartz which has been recemented by later quartz filling.

The rich ore taken from the lower workings has come from two areas, one just south of the winze connecting the upper and lower workings and the other about 700 feet north of the winze. At each place the vein is wider than the average, its width being about 7 feet at one place and 10 feet at the other. Moreover, they both lie at the north ends of marked enlargements of the vein and at nearly equal distances, about 100 feet, north of intersecting veins.

The writer had the opportunity of observing the rich ore in place in the northern stope. Here, directly beneath a well-marked hanging wall, was 1½ feet of black and gray gougey material, apparently in the main comminuted country rock, containing a few angular fragments of quartz. Below this was a very distinct band, about half an inch wide, of finely comminuted white quartz. Under the microscope this was seen to consist of angular quartz fragments varying in size from pieces a few millimeters across to minute specks barely distinguishable with the highest power. This band was separated from the vein by a narrow streak of black gougey material. The broken material lying between the hanging wall and the vein widened away from the richest ore and reached a maximum width of 12 feet a short distance to the south. For the first 10 inches the quartz of the vein was closely banded, the white quartz being separated by thin black streaks at intervals of 1 to 3 inches. The banding is due to movement and the black streaks consisted of arsenopyrite, crushed to the fineness of dust. Here and there among the dustlike fragments of arsenopyrite were small well-formed crystals that appeared to be the result of recrystallization in place of a part of the crushed and powdered arsenopyrite. Among these streaks was also a certain amount of free gold striated and polished by movement. In the quartz of the upper part of the vein were also shattered and broken crystals of arsenopyrite, with which the greater portion of the free gold was closely associated. In the quartz were small specks of sulphides, principally galena, which showed the peculiar radiate replacement structure characteristic of this mineral in the Alleghany district. Below the 10 inches of banded quartz was 3 feet of massive white quartz. This was rather coarsely crystalline and contained numerous large and small vugs lined with quartz crystals. The long axes of the larger vugs appeared to be generally parallel to the dip of the vein. Specks of gold occurred throughout this quartz but decreased in number toward the footwall. In several of the smaller vugs little crystals of gold had grown on the faces of the projecting quartz crystals. No mariposite was found in the vicinity of the rich chimney. A specimen of the rich ore is shown in figure 54.

MINNIE D. PROSPECT (2).

The Minnie D. prospect, a short distance north of the Tightner, is developed by two tunnels 60 feet apart vertically. The upper tunnel follows the vein for 150 feet and the lower for about 300 feet. The strike varies from N. 80° W. to N. 65° W. and the dip averages 46° NE. On the hanging-wall side the vein is bounded by a well-marked slip which is in places intersected at small angles by fault planes passing off into the hanging wall. On the footwall there has been but little movement and the vein cuts sharply across the schistosity of the amphibolite and is in several places joined by stringers from the footwall side.

The vein varies in thickness from a maximum of 15 inches to practically nothing, but the most usual width is about 2 inches. The quartz is distinctly banded and in places approaches comb structure. Near the walls are rare white crystals of albite. In places the quartz crystals projecting into the vugs are coated with minute crystals of siderite and of semicircular crystals of dolomite. The quartz contains nests of little pyrite crystals, accompanied by specks of sphalerite and galena. In the upper tunnel it is iron stained and in a few places shows black dendritic markings. Free gold is found where the stringers from the footwall intersect the vein. The gold is in the quartz near the sulphides and is very commonly smeared out along slips in the vein. A rare occurrence of gold was seen in the presence of minute specks on the faces of pyrite crystals.

OSCEOLA MINE (3).

The Osceola mine is above the north fork of Kanaka Creek, about half a mile northeast of the town of Alleghany. A large amount of ore has been taken out from this mine, but the production is unknown. Development work was in progress in May, 1913.

The upper tunnel, at an elevation of 4,370 feet, follows the vein for about 40 feet N. 60° W. and then for about the same distance N. 47° W. The dip is here about 55° NE. The vein consists of white quartz and is 6 feet wide at the portal and 2 feet at the face. The lower tunnel, at an elevation of 4,200 feet, has a length of 1,650 feet. The strike of the vein in the outer part of this tunnel is N. 45° W., in the central part between N. 60° W. and N. 70° W., and near the face N. 25° W. The dip shows similar variations; near the portal it is 50° NE.; in the central part it steepens to 70° or more; for the greater part of the course of the vein it is between 50° and 60°, and near the face of the tunnel it flattens to 35°. The vein has a maximum width of 10 feet, but between points 650 and 1,150 feet from the portal the quartz pinches out and the tunnel follows a crushed zone in the schist. From the 1,150-foot point to the face the quartz is continuous. Near the portal there is a split in the vein and a part goes off to the north with a dip of 60° W. but has not been prospected.

The ore, so far as could be seen, is similar to that of the other mines. In the richer patches the quartz contains narrow dark bands of crushed arsenopyrite, and near these free gold is found.

ELDORADO MINE (4).

The Eldorado mine was not in operation at the time of visit. The property is on the south bank of the South Fork of Kanaka Creek, about three-quarters of a mile southeast of Alleghany. The principal workings consist of a tunnel 1,100 feet in length, with stopes above. The country rock is amphibolite, the only notable feature of which is that here the schistosity dips at about 30°, a much lower angle than elsewhere. The vein is fairly continuous throughout the length of the tunnel. At about 500 feet from the portal a well-marked vein branches off on the footwall side. At 800 feet in the vein which up to this point has a northwesterly strike turns sharply, and within a little more than 100 feet it assumes a northeasterly direction. For about 100 feet along the turn quartz is lacking. The slickensides and grooves along the wall, which in the northwesterly course of the vein pitch to the northwest, are vertical at the turn and pitch to the southwest in the portion of the vein with the northeasterly strike.

TWENTY ONE MINE.

The Twenty One mine just south of the Tightner was idle in May, 1913, and its production is unknown. The vein has been followed for about 1,000 feet and pinches and swells greatly, quartz being absent for considerable distances. Although at a lower level than neighboring mines there appears to be more oxidation, and secondary pyrite is prominent.

SIXTEEN TO ONE MINE (5).

The Sixteen to One mine, three-quarters of a mile south of Alleghany, was located in 1908. Its production is estimated to have been between $150,000 and $300,000. The main tunnel is about 900 feet long, and all the work has been done above this level. A winze is now being sunk to develop the ore at greater depth.

The country rock is amphibolite; in places near the vein it is silicified, and along the walls it is everywhere much crushed. The average strike of the vein is northwest. The dip is to the northeast—in the raise above the adit about 30°, at the adit level 50°, and in the winze from 60° to 70°. For about 200 feet along the tunnel there is a well-defined quartz vein. Beyond is a band of gauge, in places 2 feet wide, which carries small lenses of quartz mixed with mariposite and dolomite. The pay ore occurred in a single shoot, about 80 feet in width along the drift and 100 feet up the dip, which had a pitch of 30°–40° NW. Within this shoot the high-grade ore occurred in small zones transverse to the pitch of the shoot.

SHERMAN MINE (6).

The Sherman mine, 1½ miles southwest of Alleghany, is developed by a tunnel about 1,000 feet long. The production is unknown. The vein is sinuous, the strike varying between north and N. 30° W., and the dip averaging about 60° W. At 650 feet from the portal the tunnel encountered a nearly horizontal quartz stringer, which has been followed for 450 feet. The main vein is well defined for the first 700 feet of the tunnel. Beyond this it pinches out and only small discontinuous stringers of quartz are found to a point within about 50 feet of the face, where a vein about a foot wide comes in.

The vein material is white quartz, slightly iron stained. In places it contains small inclusions of schist, and rarely small patches of pyrite associated with a little minutely crystalline arsenopyrite. Parallel to the walls are streaks of gouge containing pyrite.

KENTON MINE (7).

The Kenton is one of the older mines of the district and is supposed to have had a large production. For the last few years, however, practically no gold has been obtained. The equipment consists of a 10-stamp mill and four vanners. The principal workings consist of a tunnel and drift about 300 feet above Kanaka Creek. The crosscut tunnel is about 500 feet in length and the drift follows the vein for about 300 feet.

The country rock is, as usual, amphibolite, and the vein does not differ in type from others of the region. The strike varies between north and N. 10° E. and the dip from 45° to 50° E. The quartz is persistent and, from a minimum of a few inches, in places reaches 6 feet in thickness. No mariposite was seen. Throughout the quartz are patches of pyrite with small crystals of arsenopyrite. These, however, carry but little gold. Near the north end of the drift a marked fissure in the hanging wall coincides with the part of the vein where the best prospects in free gold were obtained. Here a single mass of coarsely crystalline arsenopyrite was found. This is described as being the size of a fist and yielded $30 in gold.

The upper workings are to the southeast of the lower and may be on a different vein, as the strike is here N. 20° W. and the dip 40°-45° NE. In places the quartz here shows dendritic manganese markings. The old stopes appear to have favored portions of the vein where the hanging-wall slip was less marked.

ORIENTAL MINE (8).

The Oriental mine is on the north side of Kanaka Creek, about 1½ miles west of Alleghany. A large amount of work has been done here in the past, but the mine has been idle for some years. On the lower tunnel, at an elevation of 4,050 feet, the vein is reached by a crosscut tunnel 4,150 feet in length. For the most part the tunnel passes through amphibolite schist, but from the 3,600-foot point to the face it is in a much-altered microcline granite, the only silicic intrusive rock seen in any of the mines. On the lower level two veins have been developed. The southern vein cuts the granite but is here small and poorly defined. The northern vein is at the northern contact of the granite and schist and has been developed only on this level. For about 400 feet the northern vein follows the contact very closely, but at the west end it passes first into granite and then into schist, and at the east end directly into schist. Between this level and the outcrop at an elevation of 4,800 feet the southern vein is developed by several levels.

The strike is variable but averages about N. 70° W. The dip, which is 30°-35° N. in the lower levels, steepens to 50° N. in the upper workings. At an elevation of 4,250 feet the southern vein passes out of the granite, and above this level it is entirely in the amphibolite, except at the west end of the 4,340-foot level, where it enters a serpentine band and breaks up into small irregular stringers.

In places the quartz pinches out for short distances, but on the whole it is fairly persistent. The greatest width observed was 10 feet. All the stoping seems to have been done along the footwall; generally the lower 2 feet of the vein has been mined. Small quartz stringers are very common in the schist near the vein. The only sulphide seen was pyrite, which occurs in the quartz in small patches half an inch across. The granite, near the vein, contains pyrite and much carbonate and is said to carry gold. In the rich ore, however, as shown by specimens collected by Mr. Hewett, there is the same association of gold and coarsely crystalline arsenopyrite that occurs in the other mines.

RAINBOW MINE (9).

The Rainbow vein, at Chips Flat, was discovered in 1885 in the course of gravel mining and is said to have produced $1,500,000. The present workings consist of two levels, entered by tunnels at elevations of 3,900 and 4,250 feet. There had been a 10-stamp mill on the property which had burned down just previous to the writer's visit. The immediate country rock of the vein is amphibolite, with a well-marked vertical schistosity which strikes N. 60° W. A crosscut to the south of the vein, however, cuts a band of serpentine about 200 feet wide which contains small tremolite veins. Near the vein the schist is in places altered to dolomite and mariposite and more rarely silicified.

On the lower tunnel the vein is reached by a 1,200-foot crosscut. Two veins have been developed to some extent. The smaller one has an average strike of about N. 15° W. and dips 65° W. This vein has been followed for about 600 feet but not stoped. The other vein has a general strike of about N. 70° W., though varying between west and northwest, and dips 30°–65° N. This vein has furnished the production of the mine. The quartz is generally between 1 and 2 feet wide, but in some places reaches 5 or 6 feet. A short distance southeast of the intersection of the two veins it is a large irregular mass about 30 feet thick. The gouge streak marking the footwall of the main vein is continuous across the minor vein. On the lower level the quartz of the main vein is continuous for about 400 feet.

The quartz is milky white but contains numerous vugs, particularly in the stopes. Some of the projecting quartz crystals in the vugs are as much as 6 inches in length. The quartz in the vugs is in many places coated with finely crystalline or chalcedonic secondary quartz and here and there with pyrite and perhaps marcasite. Bladed semicircular crystals of dolomite also project from the faces of the drusy quartz. Intersecting veins enter from both footwall and hanging wall, but a band of gouge everywhere separates the intersecting vein from the main vein, indicating later movement parallel to the strike.

The ore occurred in small rich shoots, as in the Tightner mine. So much gophering has been done by lessees that it is impossible to deduce any rule covering the occurrence. It is certain, however, that around the edges of the large mass of quartz found near the intersection of the two veins very rich masses of arsenopyrite and free gold have been taken out. The trace of the northerly vein upon the main vein would be a line rising to the east, and it appears from the old workings as if the stopes tend to follow such a line.

PLUMBAGO MINE (10).

The Plumbago mine is situated on the south side of the divide between Kanaka Creek and the Middle Fork of Yuba River. It has been worked at intervals since some time before 1860, and the production is said to have amounted to several millions. Besides the old workings along the outcrop the vein is developed by five tunnels at intervals of 100 feet on the dip of the vein. There is a 20-stamp mill in operation on the property.

The vein lies in a belt of amphibolite between two bands of serpentine. The amphibolite is less altered than usual, and specimens collected near the serpentine contact at the mine clearly show their derivation from gabbro. The amphibolite belt which contains the vein is about 300 feet wide at its widest part. It narrows to the northwest, where it passes under the gravels that cap the ridge, and it wedges out a short distance to the southwest.

The vein strikes northwest and dips 30°-45° NE. The greatest thickness observed was about 6 feet. As in the other mines the quartz forms in lenses. These are about 200 feet along the drifts and somewhat longer down the dip. The rich spots seen are irregular in distribution, but seem to follow poorly marked shoots which have a southeast pitch. The localization is considered to be due to an intersection of two veins.

On the third level and for a short distance below it is a mass of andesitic bowlders and quartz fragments, cut by a basalt dike. Presumably this material represents a Neocene volcanic vent. The basalt dike is probably of Pleistocene age, for it has the same composition as the Pleistocene basalts in the region north of Forest described by Lindgren.[1]

The ore is similar to that of the other mines in the district, small masses of high-grade ore occurring in nearly barren quartz. These patches seem to have been more or less localized along two broad southeastward-pitching shoots. The quartz outside of the high-grade pockets carries irregular amounts of sulphides, principally pyrite but including also galena, sphalerite, and chalcopyrite. The concentrates run about $50 to the ton, and there are sufficient sulphides in the vein to permit stoping the low-grade quartz.

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[1] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Colfax folio (No. 66), p. 7, 1900.

IRELAN MINE (11).

The Irelan mine is situated on the top of the ridge between the Plumbago and Gold Canyon mines, and the vein is supposed to be a continuation of the Gold Canyon vein. As in the Plumbago, the outcrop is not covered with gravel, and so the vein was discovered earlier than those of some other mines. The mine was located about 40 years ago and is said to have produced at least $300,000. Besides the old surface workings, a tunnel has been opened on the veins near the top of the hill, at an elevation of about 4,400 feet. A second tunnel is being started about a quarter of a mile to the southeast, 400 feet lower. The country rock is entirely amphibolite, but a belt of serpentine lies between the Irelan and Plumbago mines.

There are two veins here. The eastern vein strikes N. 60° W. and dips 50°–60° NE., and the western one strikes about N. 50° W. and has an average dip of 45° NE. The intersection has not yet been developed. The eastern vein has been followed about 600 feet. It pinches and swells greatly, varying from a 1-foot band of gouge and altered country rock to 6 feet of quartz. Very little mariposite was seen, and this only in close association with the country rock. Most of the quartz is banded, and bands of white quartz averaging about 3 inches in width are separated by thin dark bands which consist of altered country rock and crushed arsenopyrite. Dark transparent cryptocrystalline quartz also occurs in places in these darker bands. The quartz is vuggy and the projecting crystals of the vugs are in places coated with successive layers of minutely crystalline and chalcedonic secondary quartz.

The ore shoots appear to pitch to the southeast and are said to be more regular than in the other mines of the district, though not of such exceptionally high grade. The rich ore consists of gold-bearing arsenopyrite. Free gold is only rarely visible, but when a polished section of the arsenopyrite is examined under the microscope it is seen to be flecked with minute specks of gold. The arsenopyrite occurs in shoots in the wider portions of the veins, either in fairly definite parallel bands in the quartz or in crystalline bunches. The western vein has not yet been developed to any considerable extent. Near the southeast end of the western drift a 3-inch veinlet of quartz, carrying patches of rich arsenopyrite, 1 to 2 inches across, enters from the footwall.

GOLD CANYON MINE (12).

The Gold Canyon mine is on the north bank of the Middle Fork of the Yuba, about a mile southeast of the Plumbago. Its total production is said to be in excess of $1,500,000. There is a 10-stamp mill on the property, and the power for mill and mine is furnished by the power house belonging to the company. The mine is developed by several tunnels, the lowest of which enters a few feet above the level of the river. Below this tunnel the vein has been opened by a winze for about 200 feet along the dip. Drifts have been run from the winze at a point 160 feet down the dip from the lowest tunnel, at the tunnel level, and at the mill level, 125 feet above. The drift at the mill level is about 1,200 feet in length. The vein strikes about N. 50° W. and has an average dip of 50° or 60° NE. On the tunnel level the vein is nearly vertical, but immediately below this level it has a dip of about 50° and on the upper level it is even flatter. The vein pinches and swells to a marked extent, and the lenses appear to be roughly parallel to the slickensides on the walls, which dip about 65° SE. in the plane of the vein.

The country rock is amphibolite, which is much altered near the vein. At the southeast end of the main drift the vein passes from the amphibolite into the serpentine and within a distance of a few feet is broken up into irregular stringers.

The richest shoots appear to have been formed at the edges of enlargement in the vein, but it could not be determined whether or not they were connected with intersecting veinlets. At the time of visit a patch of quartz containing rich arsenopyrite was being stoped. Here the vein was about a foot wide, but it narrowed immediately below. Visible gold was not directly associated with the arsenopyrite, which was said to assay about $1,000 a ton, but coarse gold occurred in the constriction of the vein immediately below. (See fig. 53.) Under the highest power of the microscope, however, a few minute specks of gold, not over 0.003 or 0.004 millimeter in diameter, could be distinguished in the arsenopyrite. The arsenopyrite in the vein appears to be (in part at least) a replacement of included fragments of the country rock, for instead of being present in separate individual crystals, as in the rich ore of the Tightner mine, it occurs in small, compact, coarsely crystalline masses with fairly definite boundaries. At another point the rich arsenopyrite was found close to the footwall, but none occurred on the hanging wall.

NORTH FORK MINE (13).

The North Fork mine, near Forest, has been essentially a gravel mine, but lately exploration has been going on with a view to rediscovering a vein cut by one of the early bedrock tunnels, now caved, from which a pocket carrying $100,000 in gold was obtained. The workings consist of a 13° incline, 1,037 feet in length, and a

1,000-foot crosscut. The incline cuts a belt of serpentine, but the crosscut is entirely in the amphibolite, which is for the most part altered to a chlorite schist. At the time of visit the footwall of the vein had been cut. This wall strikes N. 38° W. and dips about 40° SW. On the wall is about 1 foot of quartz, with broken ground, consisting of crushed and much altered schist and irregular stringers of quartz, above the vein quartz. The southwesterly dip is one of the few exceptions to the general easterly and northeasterly dips which prevail throughout the region. A shaft is being sunk in the footwall, and it is planned to crosscut the vein at a depth of 75 feet.

FEDERAL PROSPECT (14).

The Federal prospect, near Forest, has a tunnel about 1,000 feet long which in a general way follows the contact of amphibolite and serpentine, varying in direction between S. 20° E. and S. 50° E. A few small quartz veins have been cut but none developed.

KATE HARDY MINE (15).

The Kate Hardy mine has a reported production of $225,000 and has been worked at intervals since about 1860. The present equipment consists of a three-stamp mill and one classifier. The vein outcrops in the Cape Horn slate on the south bank of Oregon Creek, about 300 feet west of the serpentine contact. The slate is fine grained and much sheared, and contains small lenses of blue-gray quartz free from any mineralization. Near the vein the slate has a distinctly talcose and in places a graphitic appearance. The outcrop of the vein is much more prominent than is usual in this region and can be traced up the hill to the southeast until it is lost beneath the gravel and lava capping. The vein strikes about N. 20° W. and the dip varies from 80° W. to vertical. The width of the vein is between 10 and 30 feet. Development work has been carried on in four tunnels, the longest of which is about 300 feet in length.

The ore is partly oxidized, but contains considerable quantities of sulphides. Commonly these consist of small patches of finely crystalline pyrite which rarely assays over $10 to the ton. Small specks of chalcopyrite, galena, sphalerite, and tetrahedrite were observed near the rich ore. As usual in these deposits, the pay ore occurs in small patches of extremely rich ore consisting of free gold associated with auriferous arsenopyrite. The visible gold occurs both in the partly oxidized arsenopyrite crystals and in the quartz near by. The gold ranges in value from $16.30 to $16.75 an ounce. The patches of rich ore have been found only along the footwall and were all small. The smallest found carried $9 in gold, and the largest yielded over 500 pounds of rich ore, containing $20,000 worth of gold. Up to the present time the hanging wall has not been prospected.

On the north side of Oregon Creek the vein splits and has not been developed. It is said to be the same vein which has been worked at the Brush Creek mine, near Mountain House.

○

R H Crawford

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 580—J

THE PHOSPHATE DEPOSITS OF SOUTH CAROLINA

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BY

G. SHERBURNE ROGERS

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1913, PART I—J

WASHINGTON
GOVERNMENT PRINTING OFFICE
1914

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
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THE PHOSPHATE DEPOSITS OF SOUTH CAROLINA.

By G. SHERBURNE ROGERS.

INTRODUCTION.

The deposits of phosphate rock in the vicinity of Charleston, S. C., were among the first discovered in the United States, and until about 20 years ago the field was one of the largest producers in the world. The workable deposits are confined to the region lying in general between Charleston and Beaufort and extending about 25 miles back from the coast. The phosphate rock occurs in a thin bed which underlies irregular areas within the region defined. This bed is commonly less than 18 feet below the surface, and is thus comparatively easy to mine, but, owing to the rather low grade of the rock and the exploitation of richer and more easily accessible deposits in Florida and Tennessee, production in the South Carolina field has now almost ceased. A number of papers describing this field have been published, most of them 20 years or more ago, but in view of the present more extended geologic information concerning this region it has been thought advisable to prepare this account, which is based on a brief field study by the writer.

The examination of the field was made in January, 1914. The writer is indebted to Mr. Earle Sloan, formerly State geologist of South Carolina, for many courtesies and for some unpublished information concerning the geology. Mr. John Hertz, who has long been engaged in phosphate mining, kindly contributed several maps and furnished valuable data, and Messrs. William Gaillard, Bachman Smith, and William Alston assisted in many ways. In addition to information privately communicated, several of the earlier reports on the field have been freely drawn upon for pertinent facts.

The earliest report on the phosphate deposits was published in 1868 by N. A. Pratt,[1] and this was followed in 1870 by a more extended account by F. S. Holmes.[2] Both of these papers are written in narrative and more or less popular form. In 1870 N. S. Shaler[3] contributed a short scientific description. In 1880 C. U. Shepard, jr.,[4] published the most complete and valuable of the earlier reports on the field. In 1888 R. A. F. Penrose, jr.,[1] wrote for the United States Geological Survey a bulletin on phosphate which contains a good though brief account of the South Carolina deposits. In 1891 a book on American phosphate by Francis Wyatt[2] appeared, in 1892 a book on phosphate by C. C. H. Millar,[3] and in 1895 a study of the phosphate industry by David Levat,[4] all three of which deal with the South Carolina field at greater or less length, but discuss chiefly the mining and product costs. Charles L. Reese[5] published a short paper on the region of the deposits based on a series of chemical experiments. An extended account of the field and narrative of its discovery and history, prepared primarily for newspaper publication, was written by P. E. Chazal[6] in 1904. In 1908 Earle Sloan,[7] State geologist, published a "Catalogue of the mineral localities of South Carolina," which contains geologic sections measured at a number of places and a short account of the phosphate. In 1913 William H. Waggaman,[8] of the United States Department of Agriculture, wrote a brief report on the field, dealing chiefly with the state of the industry and methods of production. In addition to these general papers, an elaborate description by Joseph Leidy[9] of the vertebrate fossils found in the phosphate beds appeared in 1881, and a brief account of some of the invertebrate forms by W. H. Dall[10] in 1894.

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[1] Ashley River phosphates, Philadelphia, 1868.

[2] Phosphate rocks of South Carolina, Charleston, 1870.

[3] On the phosphate beds of South Carolina: Boston Soc. Nat. Hist. Proc., vol. 13, pp. 222-235, 1870: U. S. Coast Survey Rept., pp. 182-189, 1870.

[4] South Carolina phosphates, Charleston, 1880.

GEOGRAPHY AND TOPOGRAPHY.

The phosphate deposits are confined to a seaboard zone, most of it less than 30 miles in width, which extends from Beaufort on the south to a point about 20 miles beyond Charleston on the north. (See Pl. II.) The most important deposits, however, are situated between the mouth of Broad River and a point near the source of Wando River and lie within a rough arc terminating at these points and extending farthest back along Edisto River. Within this segment the phosphate underlies irregular areas whose boundaries have not been exactly defined but which are approximately delimited on the accompanying map.

The principal cities within this area are Charleston and Beaufort, the former being the center of the phosphate and fertilizer industry.

---

[1] Nature and origin of deposits of phosphate of lime: U. S. Geol. Survey Bull. 46, pp. 60–70, 1888.

[2] Phosphates of America, pp. 44–61, New York, 1891.

[3] Florida, South Carolina, and Canadian phosphates, pp. 123–178, London, 1892.

[4] Industrie des phosphates et superphosphates, pp. 83–90, Paris, 1895.

[5] On the influence of swamp waters in the formation of the phosphate nodules of South Carolina: Am. Jour. Sci., 3d ser., vol. 43, pp. 402–406, 1892.

[6] Sketch of the South Carolina phosphate industry, Charleston, 1904.

[7] South Carolina Geol. Survey, 4th ser., Bull. 2, 1908.

[8] Report on the phosphate fields of South Carolina: U. S. Dept. Agr. Bull. 18, 1913.

[9] Description of vertebrate remains, chiefly from the phosphate beds of South Carolina: Jour. Acad. Nat. Sci. Philadelphia, vol. 8, 2d ser., pp. 209–262, 1874–1881.

[10] Notes on the "land phosphate" of the Ashley River district, S. C.: Am. Jour. Sci., 3d ser., vol. 48, pp. 300–301, 1894.

U. S. G

In previous years a large amount of phosphate rock was shipped from these points or from docks located farther up the rivers in their vicinity. The Atlantic Coast Line, the Southern Railway, and the Charleston & Western Carolina Railway cross the area, and most of the phosphate properties are located either on the main lines or on short spurs of these roads.

The coast in this vicinity is low and extremely irregular in outline and is bordered by numerous islands. It is intersected in the most intricate manner by numberless tidewater channels which range in width from a few feet up to several miles, one of the widest being Broad River at Port Royal. Many of these channels run almost parallel to the coast and thus form islands, and in some localities they have intersected the coast to such an extent that two or three tiers of islands have been formed.[1] In addition to these arms of the sea, many of which extend considerable distances back from the coast proper, some of the streams and rivers that traverse this region have developed a system of tidewater distributaries. Edisto, Ashepoo, and Broad rivers are conspicuous examples of streams of this type, which, in conjunction with the waterways mentioned above, have intricately dissected the general coastal region. (See Pl. II.) Most of the rivers are broad, sluggish streams and are navigable for considerable distances above their mouths, affording ready means of transportation for the phosphate.

The topography within the whole phosphate-bearing area is very uniform, being everywhere of the Coastal Plain type. The land is almost flat and is for the most part less than 15 feet above tide; elevations of more than 25 feet are uncommon. Most of it is wooded and is swampy in character, being practically covered with water for at least part of the year. In the course of the phosphate mining during the last 45 years many large areas have been worked over with steam shovel or by hand, and these tracts, in which the surface is broken, swampy, and covered with dense thickets, are now practically impassable.

GEOLOGY.

STRATIGRAPHY.

SEQUENCE OF THE STRATA.

Owing to the wealth of fossil remains which some of the strata in this region contain they have attracted the attention of many observers. Ruffin,[2] Tuomey,[3] Pratt,[4] Holmes,[5] and Shepard,[6] all give more or less extended descriptions of the geology. Their work has been largely superseded, however, by the detailed investigations of Sloan[1] and the broad areal studies of Vaughan.[2] In conformity with the results of this recent work the following classification has been adopted by the United States Geological Survey for the formations treated in this report:

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[1] A good account of the configuration of the coast, the submarine topography, etc., is given by N. S. Shaler in U. S. Coast Survey Rept., 1870, pp. 182-185.

[2] Ruffin, Edmund, Agricultural survey of South Carolina, Columbia, 1843.

[3] Tuomey, Michael, Report on the geology of South Carolina, Columbia, 1848.

[4] Pratt, N. A., Ashley River phosphates, Philadelphia, 1868.

[5] Holmes, F. S., Phosphate rocks of South Carolina, Charleston, 1870.

[6] Shepard, C. U., jr., South Carolina phosphates, Charleston, 1880.

Geologic formations related to the phosphate deposits of the Charleston region, S. C.

System.	Series.	Formation.	Approximate. thickness.	Character.
Quaternary.	Pleistocene.	Undifferentiated.	*Feet.* Variable.	Sand, gravel, loam, etc.
		Unconformity		
Tertiary.	Pliocene.	Waccamaw marl.	11	Compact granular marl; upper part brownish yellow, lower part gray.
		Unconformity		
	Miocene.	Duplin marl.	35	Yellow marl; upper part very hard, characterized by *Pecten eboreus;* middle compact to porous, containing *Chama striata* and *Arca incile;* lower friable and porous, containing *Amusium mortoni.*
		Unconformity		
		Edisto marl.	0-4	Marl, commonly more or less phosphatized; compact in texture, but containing many large cavities; color light where unaltered, darker where phosphatized; source of the commercial phosphate.
		Unconformity		
	Oligocene.	Apparently unrepresented in this area.		
	Eocene.	Cooper marl.	100+	Marl, light grayish green to dark greenish drab.

TERTIARY SYSTEM.

EOCENE SERIES.

Cooper marl.—The Cooper marl is the lowest formation here considered, though earlier Eocene is well developed within the general phosphate-bearing area. The Cooper conformably overlies the Barnwell sand (equivalent in part to the Mount Hope marl of Sloan), which is the highest formation of the Claiborne group in this region. The Cooper is therefore in whole or in part referable to the Jackson group, the highest division of the Eocene, but diagnostic fossils are rare and the exact age of the upper part of the formation has not yet been determined. The Cooper is, however, almost entirely late Eocene, but its higher strata may have been deposited in early Oligocene time.

The formation consists of over a hundred feet of grayish-green marl; the lower part (the Cooper marl of Sloan) is greenish drab in color and somewhat plastic when wet, but lighter colored and fairly hard when dry. It commonly contains about 75 per cent lime carbonate and about 2 per cent lime phosphate. The upper part of the formation (the Ashley marl of Sloan) is dull olive green and semiplastic when wet and drab when dry. The content of lime carbonate is somewhat lower than that of the lower division of the formation, but the phosphate is considerably higher, commonly exceeding 5 per cent. (See analyses, p. 208.)

---

[1] Sloan, Earle, South Carolina Geol. Survey, 4th ser., Bull. 2, 1908.

[2] For discussion by Vaughan see Willis, Bailey, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, pp. 806-813, 1912.

Shepard[1] gives an interesting well section made at Sineaths station, which presumably includes the greater part of the Cooper and probably also part of the underlying Claiborne group. The section is, unfortunately, not complete, but gives only the depth of certain strata which Shepard analyzed for phosphate. (See analyses, p 208.) It shows, however, that thin layers of large nodules containing 50 per cent or more of phosphate occur at depths of 26, 70, and 110 feet below the surface, and that the inclosing marl contains phosphate in amounts varying from a trace to 3 per cent.

The exact thickness of the Cooper marl has not been determined. The Cooper is being quarried at Woodstock, about 15 miles north of Charleston. At the time of the writer's visit only about 65 feet was exposed, but it is reported that the base of the marl had been reached by drilling to a depth of 140 feet. It is possible, however, that this may include part of an underlying formation. An excellent section of the Cooper is exposed at the Woodstock pit, from which about 5,000 tons a year is quarried for use as a base or "filler" for the commercial fertilizer. The marl is sufficiently coherent to form the vertical walls of the deep pit, yet soft enough to be worked with pick and shovel. It is blasted out, broken up, and transported by bucket hoist to the shed, where it is burned and ground. The marl is compact and impervious to water, so that the pit is fairly dry. Invertebrate fossils are rather scarce, but fragments of bone are not uncommon.

OLIGOCENE SERIES.

In the phosphate area the Oligocene is apparently not represented, and the Edisto marl (Miocene), the source of the phosphate with which this paper is primarily concerned, rests directly on the Cooper marl (Eocene).

It may be pointed out, however, that the absence of Oligocene strata does not necessarily imply that they were never deposited. The Cooper marl may overlap slightly into Oligocene time (see p. 186), and this suggests that there may have been no marked break at the end of the Ecoene and that deposition may have continued for some time. If it did, then all the strata down to the present top of the Cooper must have been eroded during the subsequent elevation of the land.

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[1] Shepard, C. U., jr., Rural Carolinian, August, 1873. See also Chazal, P. E., loc. cit., and Waggaman, W. H., loc. cit.

MIOCENE SERIES.

Edisto marl.—In this region the Edisto marl, the source of the phosphate rock, rests directly and unconformably on the Cooper marl, the hiatus representing all or nearly all of the Oligocene as well as the lowest Miocene. Similarly, the Edisto is commonly overlain directly by the Quaternary, although two higher Tertiary formations are well recognized in this general area. Although its identifiable fossils are few the Edisto is believed by Vaughan [1] to be middle Miocene—about equivalent to the St. Marys formation of Maryland and Virginia. The opinions of the older workers as to the age of the Edisto differed widely. Tuomey[2] referred it to the Eocene; Holmes, Shepard, and Chazal considered it an altered conglomerate of Eocene marl deposited in post-Pliocene time; and Pratt believed it to be Recent. Dall[3] in 1894 first definitely established its age as Miocene.

According to Sloan [4] the Edisto in its unaltered form is a yellow-white marl, commonly 4 to 5 feet thick. Although compact in texture it is penetrated in many places by tortuous cavities, some organic in origin and others apparently due to solution. It has been found in its unaltered form at only a few localities, being commonly phosphatized. The two forms may be observed in close proximity in the bed of Stono River near the mouth of Wappoo Cut. In the phosphatized form the bed is generally thinner, averaging about 1 foot and at few places exceeding 2½ feet. The phosphatized mass is fairly hard and is irregular in outline and honeycombed with many cavities. These may reach 4 inches or more in diameter and in some localities are so large that the rock is mostly broken up into irregular nodules. The filling of the cavities (or of the matrix when the bed is separated into fragments) is a black sandy clay, generally calcareous and phosphatic and in many places carrying abundant vertebrate remains. These are chiefly cetacean bones and sharks' teeth and vertebræ, but the coprolites and bones of late Miocene, Pliocene, and Quaternary land animals are also plentiful. A few distinctively Eocene shells, generally waterworn, are also found in this material. The phosphate rock itself, however, contains numerous casts and molds of the same shells that characterize the unaltered Edisto marl.[5]

In addition to this regularly stratified form the phosphate rock is also found in irregular deposits in the beds of many of the rivers.

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[1] U. S. Geol. Survey Prof. Paper 71, p. 807, 1912.

[2] Tuomey, Michael, op. cit., pp. 164-165.

[3] Am. Jour. Sci., 3d ser., vol. 48, pp. 300-301, 1898.

[4] Sloan, Earle, op. cit., p. 470.

[5] Idem, p. 299.

This river rock generally consists of rounded pebbles, and is commonly darker in color and higher in specific gravity than the ordinary land rock. It is probable that these deposits were in part laid down during Edisto time, but that they were subsequently worked over by river action and were increased in thickness by the erosion and concentration of the land deposits.

Duplin marl.—The Duplin marl, an extension of the marl of the same name in North Carolina, includes the "Peedee" and "Goose Creek" marls of Sloan. It is upper Miocene in age. The lower part of the Duplin marl (the "Goose Creek marl" of Sloan) is a soft yellow porous marl containing over 80 per cent of carbonate of lime. According to Sloan it overlies the unphosphatized Edisto[1] at Givhams Ferry, and its outcrop near Goodrich station sharply delimits on the south that of the phosphatized Edisto.[2] At the latter place it contains near the contact nodules of phosphate rock that prove it to be younger, but although it presumably overlies the phosphate to the south it was not actually observed in this position. Except for these two localities the Edisto and Duplin marls have not been observed in the same section and in the main appear to occupy different areas.

The soft yellow porous marl is overlain in places by 25 feet of harder and more compact yellow marl, to which Sloan has applied the name "Peedee marl." There appears to be no significant faunal or lithologic differences between the two, however, and they are therefore grouped by Vaughan under the name Duplin marl. The upper member ("Peedee marl" of Sloan) has not been observed in contact with the Edisto.

PLIOCENE SERIES.

Waccamaw marl.—The Pliocene series in South Carolina is represented by the Waccamaw marl, which occurs only in Horry County near the North Carolina-South Carolina State line. It is not found in contact with the Edisto, the phosphate-bearing formation, and is here included for the sake of completeness. It is described by Sloan as a compact granular marl about 11 feet thick, brownish yellow at the top and gray beneath.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

The Pleistocene deposits have been differentiated by Sloan into a number of subdivisions, but as their broader relations are not well established they are here treated as a unit. Because of the conditions described above, the Pleistocene generally rests directly on the Edisto within the phosphate-bearing area and constitutes the overburden which must be removed in mining. It consists of clay, marl, sand, and gravel, 20 feet or more in thickness. This material has been divided by Sloan[1] as follows:

---

[1] Sloan, Earle, op. cit., p. 283.

[2] Idem, p. 291.

5. Sea Island loams. Fine, glauconitic sand and silt, probably derived from the reworking of the Bohicket marl sands.
4. Wando clays and sands. White sand overlain by drab to red clay.
3. Accabee gravels, generally absent. Pebbles of quartz and phosphate rock derived from the reworking of the Edisto marl.
2. Bohicket marl sands. Fine-grained, greenish to bluish-green glauconitic sand.
1. Wadmalaw marl. Greenish-gray sandy marl inclosing large numbers of Pleistocene shells.

This classification appears to hold within the phosphate-bearing area, although the complete section is probably not exposed at any one place. In addition Sloan differentiates what he calls the Tenmile sands, which were deposited in early Pleistocene time in the form of a barrier ridge, on the seaward side of which the above-mentioned deposits were laid down.

Sloan's Wadmalaw marl is in general only 2 to 3 feet thick and is fairly persistent. It is overlapped by his Bohicket marl sands, which extend several miles beyond it to the north and are almost invariably present in the material overlying the phosphate and in places are 10 feet or more thick. These deposits are somewhat glauconitic and at the Bolton mines contain 2.19 per cent of potash. The Accabee gravels of Sloan form an interesting example of the reworking of an older bed. According to Sloan the material was derived from the partial disruption of the shoreward edge of the Edisto marl by wave action, especially in the Wando and Cooper basins. The area of the gravel is very small; where present it is generally less than a foot thick, though in places it attains a thickness of 4 feet. It has afforded a limited supply of phosphate and is known to the miners as the "Flying Rock bed." The Wando clays and sands of Sloan overlie the gravel in places, the sands being widely distributed. Sloan's Sea Island loams are best developed along the zone of the sands to which he applied the name "Bohicket" and are probably derived from them.

The character of the Pleistocene deposits that overlie the Edisto is illustrated by the following sections:

Section at Bolton mine, Charleston County.[2]

	Feet.
Vegetable muck	4
Clay, green, sandy, glauconitic (Bohicket of Sloan)	5
Sand (Bohicket of Sloan)	3
Marl, highly fossiliferous (Wadmalaw of Sloan)	2
Phosphate rock (Edisto)	2
	16

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[1] Sloan, Earle, op. cit., pp. 480-484.

[2] Idem, p. 298.

Section near Lambs, Charleston County.

[Measured by G. S. Rogers.]

	Feet.
Vegetable muck	1
Sand, white, brownish at top (Wando (?) of Sloan)	6
Sand, yellow	1
Sand, bluish-green, clayey (Bohicket of Sloan)	3
Phosphate rock (Edisto)	1
	12

Section at Simmons Bluff, Youngs Island, Colleton County.[1]

	Ft.	in.
Soil, sandy	2	0
Wando (?) of Sloan:		
Loam, red, becoming clayey toward base	6	0
Clay, white, sandy, plastic	1	6
Sand, white, fine	1	6
Bohicket of Sloan:		
Clay, green, glauconitic	3	0
Wadmalaw of Sloan:		
Loose shells	3+	
	17+	

STRUCTURE.

The strata in the South Carolina phosphate area have undergone little or no tilting and for the most part lie almost flat. Such variations from the horizontal as they exhibit are due chiefly to the character of the old surface on which they were deposited. All the formations have a slight but gentle dip toward the sea owing to the shelving character of the old surface; and as this surface was in places irregular most of the formations vary considerably in thickness and in some localities are absent.

GEOLOGIC HISTORY.

During late Eocene time the region here considered was covered by the sea and the submergence may have extended into early Oligocene time. During this period the Cooper marl was laid down to a thickness of over 125 feet. At some time during the Oligocene the land was elevated and remained above the sea for a long time, during which a portion of the upper part of the Cooper was removed by erosion. According to Sloan the shore line during this period was roughly coincident with the present position of Wando and Stono rivers. (See Pl. II.) At the opening of the middle Miocene the land was again partly submerged, and the Edisto was deposited on the irregular upper surface of the Cooper. The hills of the old surface were perhaps in part submerged and in part formed low islands, on which the Edisto was never laid down. This formation thus appears to be entirely lacking in the area between Ashepoo and Combahee rivers and in several smaller districts. The old surface was somewhat shelving, as is indicated by the present slight dip (3.3 feet to the mile) of the Edisto toward the sea. Farther seaward this inclination of course increased, and the Edisto therefore dips sharply below the present surface along the southern boundary of the phosphate area, as indicated roughly on the map (Pl. II). Thus, according to Shepard,[1] the Edisto at Charleston is about 60 feet below the surface. After its deposition the Edisto marl underwent certain chemical changes, which increased its phosphate content. (See p. 206.)

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[1] Sloan, Earle, op. cit., p. 300.

At the end of Edisto time a slight elevation of the land took place and the Duplin marl was laid down within the area which still remained below water. A further elevation of land occurred at the end of Miocene time, and no more marine sediment was laid down in the immediate phosphate area until the Pleistocene.

According to Sloan the earliest Pleistocene formation is his Tenmile sands, which were deposited in the form of a barrier ridge along a zone near the north border of the phosphate area. During the gradual subsidence which followed, the deposits called by Sloan the Wadmalaw, Bohicket, and Accabee were deposited against the seaward side of this ridge as a progressively overlapping series. The relations of the deposits to which he gave the names Wando and Sea Island are less clear, but they appear to have been laid down during the gradual reelevation which doubtless brought the land to its present altitude.

PHOSPHATE ROCK.

PHYSICAL CHARACTER.

The phosphate was described by Pratt in 1868 and by Shepard in 1880 as essentially nodular in character, and this description has apparently been followed by most subsequent writers. From a commercial standpoint this description is sufficient, for the land phosphate as mined generally occurs in small and more or less rounded fragments, and the river rock, which was extensively mined in the early days of the industry when the term was first used, is decidedly nodular in appearance. Geologically, however, the term is unfortunate, for it implies much in the way of genesis and history that is probably incorrect.

The two varieties of the phosphate, land rock and river rock, differ somewhat in character. The land rock occurs in a more or less irregular bed which represents the undisturbed phosphatized Edisto marl; the river rock probably consists in part of the original phosphatized Edisto and in part of fragments derived from the land deposits and concentrated on the river bottom, the whole deposit having been more or less worked over by river action. To these may be added a third kind, the Accabee gravels of Sloan, which are a later deposit formed by the reworking of the original bed.

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[1] Shepard, C. U., jr., South Carolina phosphates, p. 20, Charleston, 1880.

The land rock occurs in a bed which has a maximum thickness of 30 inches, but averages probably between 8 and 16 inches, and is in many places absent. It generally consists of an irregular or even jagged mass of rock honeycombed by many tortuous cavities, but its upper surface is in many places smoother and more compact than the lower. In places the cavities are as much as 4 inches in diameter and thus afford lines of weakness which cause the bed to break up easily when disturbed in mining. The cavities are probably due chiefly to solution; their interiors are generally smooth, and when the rock is broken up a fragment resembles a very irregular nodule, the surface of which is partly smooth and partly rough and broken. Associated with the rock is a black sandy clay which contains a minor amount of small rounded phosphate nodules.

The term nodule was applied by the earlier writers to the whole mass, and even the large pieces removed in mining were described as "made up of nodules cemented together." Loosely scattered nodules are referred to by some of the older writers,[1] however, and it is probable that the solvent action was sometimes strong enough to enlarge the cavities until the mass was actually broken up. Some of the fragments are described as coated with a hard and lustrous enamel, but so far as can now be ascertained such fragments were of the river variety. No instance of concretionary structure in land rock is mentioned by any of the earlier writers. Moreover, the rock contains many casts and molds of the same species that characterize the unaltered Edisto marl,[2] and there seems little doubt that it is really a bed of irregularly phosphatized marl rather than a mass of concretionary nodules.

The rock varies considerably in color, hardness, and specific gravity, these characters being partly dependent on the degree of phosphatization. Much of the material now being mined is light yellowish brown in color and is soft and chalky. All variations in color from light brown to very dark gray are exhibited, and as the color deepens the hardness and specific gravity increase. A dark rock generally contains more lime phosphate per unit volume than a light-colored one and is therefore considered more valuable.

The cavities in the phosphate rock are filled with sandy clay, which is generally calcareous and somewhat phosphatic. Its color appears to depend largely on that of the rock with which it is associated. In places this material contains quartz pebbles and pebbles or small nodules of phosphate rock. It also carries the abundant remains of many species of vertebrates which are not found within the rock mass itself.

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[1] Shaler, N. S., On the phosphate beds of South Carolina: Boston Soc. Nat. Hist. Proc., vol. 13, pp. 222-235, 1870.

[2] Sloan, Earle, op. cit., p. 299.

The river rock occurs generally in loose and more or less rounded fragments of nodular aspect, which have accumulated in irregular banks on the river bottoms. In many localities they are well rounded and are inclosed by hard lustrous enamel. Penrose [1] distinguishes six different varieties of the river rock by their color and the presence or absence of enamel. The river rock is generally darker in color than the common land variety, being dark brown or gray or even jet-black. It is higher in specific gravity than the ordinary land rock and is generally harder, especially when inclosed by enamel. Some varieties are highly siliceous, the grains of sand being visible to the naked eye. According to Penrose some of the rock from Bull River exhibits a distinct concretionary structure, but this is very uncommon. In Morgan River and elsewhere the river rock has been found in a thin and more or less continuous bed like that of the ordinary land deposits, but it generally occurs in thick but irregular banks. Some of these deposits are fairly free from mud and sand and yield a product which requires little washing. In others the proportion of matrix is greater and may increase laterally until the phosphate is too sparsely scattered to allow mining. As would be expected in a river deposit, the distribution of the rock is generally very irregular, as is also the character of the overlying and underlying material. Where the river rock occurs as a more or less continuous and undisturbed bed it appears to rest upon the Cooper marl, but in its more common reworked condition it is generally separated from the marl by clay or sand.

Some writers have differentiated a third type which they call marsh deposits. These occur in a bed similar to the ordinary land deposits, but have the dark color and higher specific gravity of the river rock. They represent merely the undisturbed phosphate bed which has undergone certain changes. (See p. 209.)

The irregular deposits of phosphate and quartz pebbles known to the miners as the "Flying Rock bed" (the Accabee gravels of Sloan) are derived from the reworking of the original land deposits. They are chiefly of scientific interest, although at some places they have yielded a limited amount of phosphate.

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[1] Penrose, R. A. F., jr., Nature and origin of deposits of phosphates of lime: U. S. Geol. Survey Bull. 46, pp. 60–70, 1888.

CHEMICAL COMPOSITION.

The commercial rock varies greatly in phosphate content, but at no place does it contain more than 64 per cent in the washed but unburned condition. Waggaman[1] states that isolated fragments have been found which contain as much as 75 per cent, but these do not occur in commercial quantity. Some of the rock mined in the Edisto district averages 62 per cent (see analysis 7, p. 196), but it is probable that the general average for the South Carolina area would approximate 58 per cent. There are many districts in which the phosphate content is as low as 55 or 53 per cent.

According to Shepard,[2] who made many hundred analyses of the South Carolina phosphate, the composition varies greatly in even one piece of rock. Thus the upper portion of the bed, which is generally flat and compact, is commonly somewhat higher in phosphate than the lower, more irregular, honeycombed portion. Similarly the exterior of a river nodule, especially when coated with enamel, may run 2 per cent or more higher in phosphate than the interior. The composition of the rock from a broad district is naturally even more variable, and irregular areas are sometimes found in mining in which the rock is of too low grade to work. The composition of the average commercial product, however, is fairly uniform.

In the following table are given fourteen analyses of the average commercial South Carolina product compiled from various sources, and three type analyses of the commercial Florida rock, inserted for comparison:

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[1] Waggaman, W. H., Report on the phosphate fields of South Carolina: U. S. Dept. Agr. Bull. 18, p. 6, 1913.

[2] Shepard, C. U., jr., South Carolina phosphates, p. 21, Charleston, 1880.

Analyses of phosphate rock from South Carolina and Florida.

	South Carolina.														Florida.		
	Land rock.							River rock.									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Insoluble	11.37	11.89	9.06	13.03	9.70	9.16	7.75	11.55	12.41	13.30	9.06	12.06	24.02	22.27	3.90	8.49	9.28
Al_2O_3	......	......	......	.40	......	3.62									1.73	1.49	1.63
Fe_2O_3	......	......	......	1.38	......		......	......	......	......	......	......	......	......	.52	.65	1.19
MgO	......	......	......	Trace.	......	......	......	......	......	......	......	......	......	......	......	.26	5.37
CaO	......	......	......	39.10	......	......	......	......	......	......	......	......	......	......	51.20	47.07	45.82
P_2O_5	27.01	26.68	27.26	27.23	26.98	......	28.47	25.61	26.68	25.14	27.26	25.14	22.36	24.51	36.80	35.11	33.07
SO_3	......	......	......	1.45	......	......	......	......	......	......	......	......	......	......	......	......	......
CO_2	4.47	3.51	3.54	3.05	......	......	3.78	4.68	4.28	3.61	3.79	4.89	3.36	1.71	......	5.54	1.64
H_2O at 100°	.00	......	.84	2.43	.91	......	......	3.68	......	.79	.57	3.85	4.79			.00	.45
H_2O combined	5.26	6.58	4.22	5.68			5.87	4.78		5.80	4.31			......	......	1.39	1.55
Organic matter					......	......			......			4.81	3.45	3.42	......	......	......
Undetermined	......	......	......	5.25	......	......	......	......	......	......	......	......	......	......	5.85	......	......
Equivalent $Ca_3(PO_4)_2$	58.95	58.25	59.51	59.44	58.92	60.46	62.14	55.91	58.24	54.88	59.51	54.88	48.81	53.51	80.33	76.65	72.19
Equivalent $CaCO_3$	10.16	7.98	8.04	......	......	9.64	8.59	10.64	9.73	8.20	8.61	11.11	7.64	3.90	......	......	3.72

1. Ashley River district; cargo sample. Shepard (Chazal, op. cit., p. 13).
2. Ashley district (between Junction and Tenmile Hill). Chazal (op. cit., p. 15).
3. Chisholms Island (Coosaw River district). Shepard (Chazal, op. cit., p. 13).
4. Bulow mines. Chazal (op. cit., p. 11).
5. Cooper district; average of four analyses. Chazal (op. cit., p. 14).
6. Edisto district (west of Edisto River); average of over 100 analyses. Chazal (op. cit., p. 15).
7. Edisto district (near Ashepoo River); average of 5 analyses. Chazal (idem).
8. Stono River—light-colored rock. Shepard (Chazal, op. cit., p. 13).
9. Stono River—dark-colored rock. Shepard (idem).
10. Bull River; cargo sample. Shepard (idem).
11. Coosaw River; cargo sample. Shepard (idem).
12. Upper Wando River. Chazal (op. cit., p. 14).
13. Wando River at Wando. Chazal (idem).
14. Beaufort River; average of 2 analyses. Chazal (op. cit., p. 16).
15. Hard-rock phosphate; Dunnellon district, Fla. Cargo sample. Millar (op. cit., p. 89).
16. Hard-rock phosphate; Pemberton Ferry district, Fla.; cargo sample. Millar (op. cit., p. 90).
17. Pebble phosphate, Phosphoria, Fla.; large average sample. Millar (op. cit., p. 36).

The analyses show that the percentage of phosphoric acid in the land rock is very uniform, ranging from 26.68 to 28.47, and that in the river rock it is generally lower, ranging from 22.36 to 27.26. The insoluble matter (chiefly sand) is generally higher in the river rock and reaches 24 per cent in the Wando product, though it is only 9.06 per cent in the Coosaw River product. Chazal says that the river rock generally contains more organic matter than the land rock, and Shepard says that it contains less iron and alumina, but the above analyses do not establish these differences. Despite its lower percentage of phosphate the river rock was strongly preferred in the early days of the industry, partly because of its low content of iron and alumina, which made it more attractive to the foreign trade, but chiefly because of the greater ease with which it could be mined and washed and because of its higher specific gravity, which meant a higher percentage of phosphate per unit volume handled. The difference in grade between dark and light colored rock is illustrated by analyses 8 and 9, which respectively show 55.91 per cent and 58.24 per cent of lime phosphate. The land rock of the Ashley district (analyses 1 and 2) may be taken as the general type for the whole area and as closely representing the product now being mined; that of the Edisto district (6 and 7) is exceptionally good. The river rock of the Stono and the Coosaw (analyses 8, 9, and 11) constituted the bulk of the river rock mined, but it is somewhat higher in grade than that of the other rivers.

In interpreting these analyses in a commercial way it must be borne in mind that most of them represent crude unburned rock or rock that has only been partly dried (air dried). In the calcination to which the rock is now subjected before it is sold the moisture and organic matter and part of the carbon dioxide are eliminated and the proportion of phosphate is generally increased 4 or 5 per cent thereby.

The analyses given in the table indicate that the South Carolina product can not compete with the Florida rock in quality. The present guaranties for the Florida export product are 78 per cent or more of lime phosphate and 3 per cent or less of iron and alumina. The very highest grade specimen of the South Carolina rock probably does not contain as much as 80 per cent of phosphate and the customary export guaranty in 1880 was only 55 per cent.[1] It later rose to 58 per cent and is now 60 per cent, but this is nearly as high as the South Carolina field can be expected to average, although the product of the Edisto district would approximate 61 per cent. On the other hand, however, the South Carolina rock makes an excellent acid phosphate which is in good mechanical condition for mixing purposes, and many consumers are said to prefer it on the ground that it makes a better fertilizer.

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[1] Shepard, C. U., jr., South Carolina phosphates, p. 16, Charleston, 1880.

PERSISTENCE OF BED.

In the fields and districts roughly defined below there are many small areas in which the phosphate bed is lacking or is too thin to be of value or is overlain by cover too thick to remove. Owing to the length of time over which mining operations have extended and to the large amount of phosphate already removed it is impossible to prepare a large map showing in detail the distribution of the workable rock. Considerable prospecting has been done throughout the general area, however, and maps have been prepared showing the exact thickness and distribution of the phosphate in certain tracts. The accompanying map (fig. 55), which was kindly placed at the writer's disposal by Mr. John Hertz, shows the irregularity of the phosphate stratum.

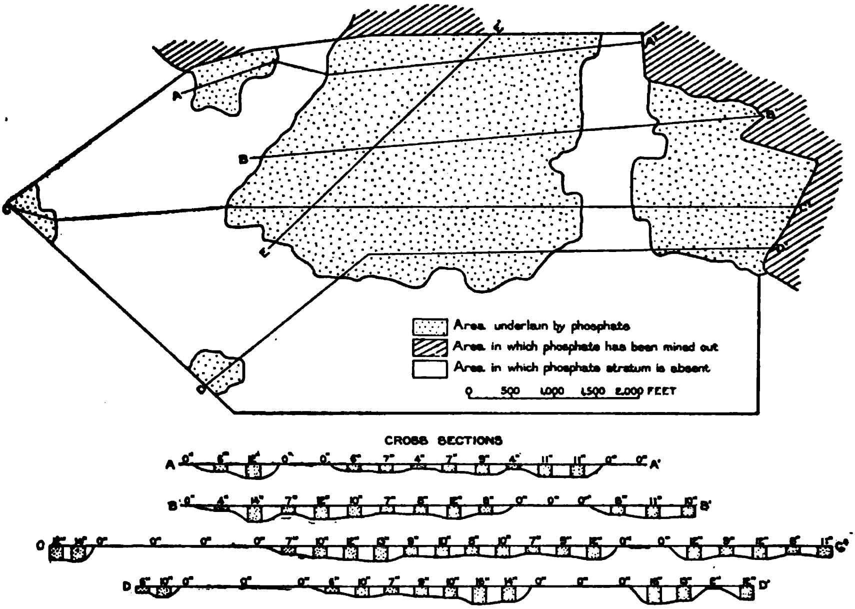
A
B
C
D
A'
B'
C'
D'
Area underlain by phosphate
Area in which phosphate has been mined out
Area in which phosphate stratum is absent
0 500 1,000 1,500 2,000 FEET
CROSS SECTIONS

FIGURE 55.—Sketch map and sections showing irregularity of phosphate stratum near north branch of Stono River, S. C.

The tract shown on figure 55 is located near the north branch of Stono River, or on the southern border of the Ashley-Cooper field, described below. The extent of the workable phosphate is shown on the map, and the thickness of the stratum is shown by sections at intervals of 400 feet, obtained in bore holes and test pits. The sections suggest that although in some places the phosphate decreases regularly in thickness and feathers out, in most places it breaks off abruptly. This general irregularity in the thickness of the stratum is probably typical of the whole area, although in places the average thickness of the rock is much greater. The irregularity is further emphasized by the difference in average thickness of phosphate under the small areas; thus the average for the small area shown at the extreme left of the map is 12 inches, that for the small area shown near the bottom of the map is only 5½ inches, and that for the largest area is 9 inches. An estimate based on these thicknesses shows that the average yield per acre in these areas would be 1,080, 316, and 675 tons, respectively. In the whole tract shown on the map the proportion of "blank" area—that in which the Edisto marl is unphosphatized or is absent—is probably larger than that in most of the Ashley-Cooper field. Thus the area prospected is 926 acres, of which only 321 acres is underlain by phosphate rock, which averages 9 inches in thickness, whereas in a tract 1½ miles to the east the 200 acres prospected proved to be all underlain by workable rock of an average thickness of 10¾ inches. On the other hand, however, random borings made at three localities several miles northeast of the first tract showed no phosphate within 20 feet of the surface.

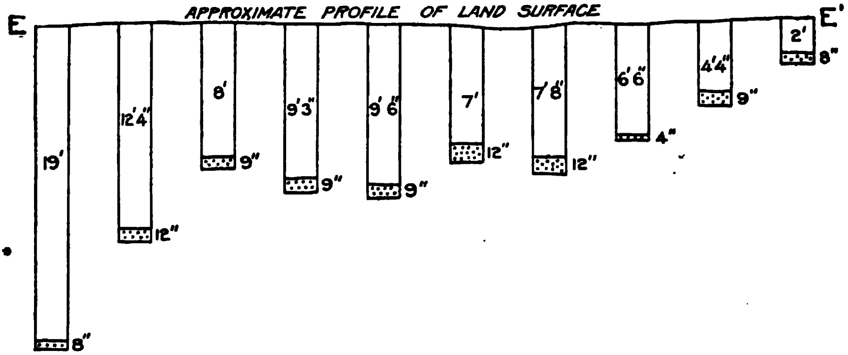

FIGURE 56.—Sections showing depth of phosphate bed below surface along line E–E′ on figure 55.

In figure 56 are given ten sections measured along the line E–E′ on figure 55 at intervals of about 360 feet. These sections show the depth of the phosphate below the surface to vary from 2 to 19 feet. Unfortunately, the absolute altitude of the surface along this line is not known, but a study of the drainage indicates that the variation in the depth of the stratum is due chiefly to the variation in its own altitude rather than to that of the land surface. This is to be expected because of the unconformable contact between the phosphate-bearing Edisto marl and the underlying Cooper marl, and affords a good example of the irregular and uneven character of the old surface on which the Edisto was laid down. In general this old surface is probably much more level than is here indicated, but in some localities, notably along Edisto River, its irregularity is even more pronounced.

The unevenness of the old Cooper surface, as shown by figure 56, suggests that in some of the areas in which the phosphate bed is thought to be absent it is merely covered by a greater thickness of overburden, and that it may therefore be somewhat more persistent than has hitherto been supposed. Owing to the fact that 20 feet is about the maximum thickness of overburden that can profitably be removed, the prospecting is generally carried only to this depth, and if the bed is not encountered it is reported absent. In some localities the operators can say with certainty that the old marl surface was reached, but in others the work done proves only that the phosphate bed does not lie within 20 or 25 feet of the surface. The presence of the bed at a greater depth has no commercial interest unless improved machinery capable of removing cheaply a greater thickness of cover is installed, but it is of distinct scientific interest in connection with the origin and geologic relations of the phosphate.

DISTRIBUTION.

All the commercially important deposits of phosphate rock lie on the seaward side of a rough arc drawn from a point near the source of Wando River to the mouth of Broad River. This area is approximately that underlain by the Edisto marl; but, as stated above, the distribution of this formation is somewhat irregular and the rock varies considerably in phosphate content, in some places being practically unphosphatized. Furthermore, in the course of mining operations during the last 45 years the phosphate has been entirely removed from tracts many square miles in extent. It is therefore impossible accurately to define the workable phosphate-bearing areas and they can be referred to only in more or less general terms.

On the map (Pl. II), however, an attempt has been made to show approximately the distribution of the phosphate. This map is based on that compiled by Shepard in 1870, but is modified because Shepard included only those areas in which the rock is within about 6 feet of the surface, whereas it has since been mined to depths of more than 15 feet. It must be borne in mind, however, that within the areas shown are many smaller districts in which the phosphate is lacking or is present at too great a depth to be workable, and many others, including practically all of the river deposits, in which it has been mined out.

In a general way the area may be divided into five fields. The Wando field contains chiefly a river deposit of rather small extent, which is now mostly worked out, but which has yielded a large quantity of fair-grade rock of the nodular form, black color, and high specific gravity characteristic of the river rock. Small areas of land rock occur along Wando River, but attempts to mine them have been unsatisfactory.

Northeast of the Wando field is the Cooper field, containing both land and river rock. The rock in this locality is of rather low grade and very little of it has been mined.

The Ashley field, a short distance northeast of Charleston, comprises about 150 square miles and is the largest and most important of all. The best deposits lie in the district along Ashley River and as far south as Rantowles Creek and Stono River. This district has been under continuous development since 1868 and has furnished by far the largest output of the land rock, having been practically the sole producer in South Carolina since 1904. The deposits on the western edge of this district are of less value than the rest, being thin, irregularly phosphatized, and in many places under considerable cover. Farther down the river, however, the rock is uniformly good, and the overburden is very regular in thickness over large areas. On the north side of Ashley River the workable phosphate has been largely mined out, but between it and Rantowles Creek large deposits still remain. In the district along the Atlantic Coast Line Railroad, especially near Mount Holly, a considerable amount of mining has been done. The best deposits are probably exhausted, for much of this area is known to be underlain by deposits which are poor or variable in character and irregular in extent. This is especially true in the district along Black and Cooper rivers, in which very little mining has been attempted.

The Stono River district, along the southern edge of the Ashley-Cooper field, has produced considerable quantities of river rock, which was of fairly high grade but which was mixed with marl and shells that were difficult to separate. Some of the earliest river mining was done on Stono River, and although the best deposits have been removed, it is possible from the more or less irregular character of the mining that some workable phosphate still remains.

The area west of Rantowles Creek almost as far as Edisto River is barren of workable phosphate, although thin deposits have been discovered at several places. Along the east bank of the Edisto a little north of the railroad a considerable amount of mining has been done, but it is reported that valuable deposits still remain.[1] Farther up the river on the east bank the rock is fairly thick and is easily accessible but is of rather low grade. River deposits occur in the Edisto itself but are so irregular that practically no mining has ever been done. The most important district of the Edisto field is that lying between Edisto and Ashepoo rivers, where many deposits of uncommonly high grade rock have been worked. According to Chazal some of the rock mined in this district contained as much as 64 per cent of lime phosphate and owing to the uniform thinness of the overburden was very easy to mine. The rich deposits are irregular in extent, however, and there are many small areas in which the phosphate content is rather low. The chief obstacle to the thorough development of this district has been its relative inaccessibility, in consequence of which many fairly rich areas remain untouched.

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[1] Chazal, P. E., Sketch of the South Carolina phosphate industry, p. 5, 1904.

The Coosaw field marks the southern extremity of the general phosphate area. Land deposits in this field are confined to the islands inclosed by Coosaw, Bull, Morgan, Johnson, and Beaufort rivers, and smaller channels. Owing to the somewhat inferior character of the rock and to the irregularity of the overburden these deposits have never been very extensively worked. By far the largest part of the great output of this field was obtained from the river deposits of the Coosaw and its smaller connecting channels. The deposits of the Coosaw itself covered 12 square miles with an average thickness of 22 inches and consisted of high-grade rock;[1] they apparently represent the concentration of the land deposits of a considerable area. Along the sides of the channels they grade into marsh deposits which were also extensively worked. The rock of Morgan River is also reported to have been high grade, and to have occurred in part as a layer 15 inches thick; similar to the land deposits. The phosphate of this district had been largely worked out by 1900, although some mining continued in the Coosaw itself until a few years later. The river deposits of Beaufort, Broad, and Johnson rivers are somewhat inferior in grade and have not contributed very extensively to the production.

QUANTITY.

Owing to the very irregular distribution of the South Carolina phosphate it is impossible to make an accurate estimate of the amount still available. Very little prospecting was done in the early days of the industry and although in recent years a large amount of exploration work has been done there are still many large areas concerning which the information is only approximate.

Shepard, in 1880, estimated the total available supply to be less than 5,000,000 tons, but over twice that amount has already been mined. Chazal, in 1904, estimated the supply still available at between 9,000,000 and 11,000,000 tons. Since that time less than 2,000,000 tons has been mined, which, according to this estimate, leaves between 7,000,000 and 9,000,000 tons. Some of this is under rather heavy cover and can not be mined at the ordinary cost, but much of it is probably comparable in accessibility and quality to that successfully mined in the past. The bulk of this phosphate is of the land variety, and is located in the areas between Ashley River and Rantowles Creek and between Edisto and Ashepoo rivers.

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[1] Millar, C. C. H., Florida, South Carolina, and Canadian phosphates, p. 156, London, 1892.

ORIGIN.

EARLIER THEORIES.

All previous observers have advanced theories of the origin of these phosphate deposits, but all the theories except Sloan's were founded on what now appears to be a misconception of the geologic relations of the deposits. However, the essential idea of most of the earlier writers, namely, that the phosphate deposits are due to a concentration of the phosphate disseminated through the Cooper marl, is probably correct, although more geologic work is required before any hypothesis can be definitely accepted or rejected. Before reviewing the earlier theories it may be well to reiterate that the phosphate deposit is not essentially a collection of nodules, but is rather a more or less continuous bed of Miocene age, which is irregular in thickness and honeycombed by cavities, and is in places found unphosphatized. (See p. 193.)

Pratt advanced the earliest theory, which ascribed the phosphate to the accumulation of bone and the other remains of vertebrate animals. This material, he thought, had accumulated somewhere in the central part of the State and after the soluble portion had been leached away and the whole mass consolidated it was brought to its present position by streams. The mechanics of the consolidating process is not clear, nor the method by which the mass could have been transported by streams and laid down as a fairly pure bed.

Holmes in 1870 advanced a theory, which was generally accepted at that time, based on the view that the bed is a collection of nodules. According to Holmes the old surface of the Eocene marl was submerged and numerous fragments were broken off by the waves and deposited in irregular basins below sea level. After the elevation of the land the sea water caught in these basins evaporated, leaving salt licks, which were visited by numerous land animals. These animals deposited in the basins their fecal, remains, bones, and bodies, and the phosphoric acid derived from this mass of organic matter later replaced the carbonate in the underlying bed of marl nodules. The chemistry of this reaction is well established, but it is difficult to understand the regular deposition of the "marl nodules" themselves or their conversion into a fairly continuous bed. Moreover, this theory is refuted by the fact that the phosphate fragments are rich in Miocene fossils, whereas the underlying marl contains Eocene fossils in much smaller numbers.

Shaler in the same year (1870) advanced a theory which is much more reasonable geologically and which fundamentally is probably correct. According to Shaler the phosphate rock is a residual crust formed by the gradual removal of the underlying marl, the carbonate having been carried away in solution while most of the phosphate remained in place. The phosphate bed would therefore be merely the topmost layer of the Eocene marl. That the theory as stated is not entirely adequate is indicated by the Miocene fossils in the phosphate.

Shepard in 1880 accepted the nodule theory of Holmes, and Penrose in 1888 followed Shaler.

Levat in 1895[1] stated that the phosphate was formed "by the transportation, after disaggregation, of the phosphatic Eocene marl and its deposition in a shallow Miocene estuary together with a variable proportion of sand and clay." He also emphasizes the fact that the bones associated with the phosphate could not have supplied the phosphoric acid, for they themselves contain more than the normal amount.

Chazal in 1904 propounded a theory essentially like that of Holmes. He believed that fragments of the Eocene marl were torn from the old surface by tidal action and were later subjected to the action of solvent waters, which dissolved away the carbonate and replaced it with phosphate. After formation the nodules "were caught up and transported by the agency of the enormous tides of the post-Pliocene seas and deposited in valleys, hollows, or old waterways." Aside from the somewhat unusual nature of this transportational process, the presence of Miocene fossils in the phosphate is incompatible with this theory.

Sloan in 1908 was the first observer, with the possible exception of Levat, to take into account the true geologic relations of the deposit. According to Sloan the land surface (Cooper marl) was submerged in Miocene time and the Edisto deposited on it as an unphosphatized marl. After the deposition of the Edisto, phosphatic sediment was laid down upon it, which ultimately phosphatized it. The phosphatic sediment was derived chiefly from the disintegration, partial solution, and erosion of the Cooper marl, but also from phosphatic organisms stranded on the coast by the Gulf Stream, and to a lesser extent from bones and other remains which accumulated after the coast was elevated above sea level. However, as the Edisto in its unphosphatized condition must have been formed of sediment derived from the Cooper marl, it is difficult to understand why so much phosphatic sediment was brought down from the same land surface immediately after its deposition. Furthermore, it seems probable that the leachings of this old surface were chiefly calcareous, and that the phosphate, being coarser, remained to a considerable extent as a residual soil, according to Shaler's view.

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[1] Levat, David, Industrie des phosphates et superphosphates, p. 83, Paris, 1895.

RESIDUAL-SOIL THEORY.

The writer's theory differs somewhat from any hitherto formulated, although involving the central idea of several of the earlier views. The fact that the phosphate is not a collection of Eocene nodules vitiates the arguments of Holmes, Shepard, and Chazal. Shaler's theory is similarly injured; for, as the Edisto is known to be marine Miocene, it must have been deposited during a distinct period of submergence. Sloan's hypothesis is unsatisfactory to the writer in that it involves the derivation of unphosphatized marl from an old land surface and a later derivation of richly phosphatic sediment from the same source. Levat's theory is not clearly expounded, but seems to approach most closely to the views advanced below.

The general conditions of sedimentation in this area have already been set forth. (See p. 191.) It seems certain that the Cooper marl formed a land surface during much of Oligocene and early Miocene time, and during this period it must have suffered considerable weathering and erosion. As this surface was not far above sea level, the amount removed by actual stream erosion was probably small in comparison with that lost by leaching and solution. The analyses given below show that the Cooper marl contains a certain amount of phosphate, which is in part disseminated through it in the form of grains and in part more irregularly distributed as nodules and to a minor extent as bone fragments, and probably also as phosphatic shells and sharks' teeth. As the Cooper land surface was gradually worn down, much of this coarser and more insoluble phosphatic material probably accumulated as a residual soil, only a part of it being carried away as sediment. Sloan [1] estimates the average phosphate content of the upper part of the Cooper to be 3 per cent (see analyses, p. 208), which gives 121 tons of 60 per cent phosphate rock per acre-foot. In other words, the disintegration of 8 feet in every acre of Cooper marl would yield about as much phosphatic material as is contained in an average acre of the phosphate bed. As a matter of fact, much of this phosphatic material was doubtless carried away as sediment; but, on the other hand, it is probable that many times 8 feet of Cooper was disintegrated and partly removed during the long period in which it remained above the sea. It may safely be assumed, therefore, that at the end of early Miocene time the old Cooper land surface was covered with a residual soil which was probably highly phosphatic in many places, though much less so in others, owing to the irregular distribution of the phosphate in the marl from which the soil was derived.

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[1] Sloan, Earle, op. cit., p. 333.

At the end of early Miocene time the region was depressed somewhat below the sea and, as indicated by the present topography and the distribution of the phosphate bed, became a great estuary or series of estuaries. As the water gradually encroached on the land the residual soil was disturbed by wave action and much of the intermixed vegetal débris removed. The areas in which the Edisto is lacking to-day were probably partly submerged islands on which wave action was sufficient to wash away the residual soil. The relief of the old surface was probably not great, however, and if certain areas were left high enough to form islands, it seems that the depression was not a great one and that the general surface was not covered with very deep water. W. C. Kerr[1] suggests that phosphatic bivalves whose shells were later broken up by wave action may have contributed phosphate. As an example, he points out that the shells of *Lingula pyramidata*, which are still found in large numbers along the coast, contain about 55 per cent of lime and magnesian phosphate. W. H. Dall, however, stated to the writer that in his opinion neither this organism nor any of the other phosphatic brachiopods were present in sufficient numbers in Miocene time to have enriched the deposit materially. At this time also fishes, amphibians, and reptiles flourished along the coast, and their fossil remains, which are now found in great numbers, probably added somewhat to the supply of phosphate. In addition to these sources, a certain amount of sediment was being received from the land during this period, and this probably also contained some phosphate. By the end of middle Miocene time, when gradual reelevation of the coast began, a deposit aggregating 5 to 10 feet thick had probably accumulated. This deposit was in general richly phosphatic, but the phosphate was probably distributed through it irregularly and in some places was present only in minor amount.

The reelevation of the land progressed until most of the areas now underlain by phosphate became a series of marshes, in which it seems certain, as Shepard, Shaler, and Chazal contend, a chemical alteration of the phosphatic marl (Edisto) would take place. The most extensive alteration would be the leaching out of the carbonate of the marl by carbonated waters, leaving most of the phosphate intact, and this process would ultimately result in converting the original 5 or 10 feet of Edisto into a thin but highly phosphatic crust. Concomitantly with this process, however, a partial replacement of carbonate by phosphate took place. Reese[2] has shown that swamp water readily dissolves phosphate, but that the phosphate is reprecipitated when the water stands in contact with lime carbonate.

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[1] Am. Naturalist, vol. 4, p. 571, 1871.

[2] Reese, C. L., On the influence of swamp waters in the formation of the phosphate nodules of South Carolina: Am. Jour. Sci., vol. 43, pp. 402-406, 1892.

This would also tend to concentrate the phosphate at the bottom of the Edisto, where the waters came in contact with the purer underlying marl, and would furthermore tend to destroy the original forms in which the phosphatic material was scattered through the Edisto. The original Edisto marl was thus largely removed by solvent action, but most of its phosphatic material, chiefly in a reworked condition, was retained. Reptiles and amphibians continued to flourish during this period and in addition a few land animals frequented the marshes. Their bones are found to-day on the phosphate bed and intermingled with it but not actually incorporated in the mass. These bones have themselves been phosphatized, perhaps in part through the agency of other bones now entirely dissolved, and probably only a minor amount of the phosphate in the Edisto itself can be attributed to these remains.

The theory above outlined seems to account for all of the known facts. The presence of a few worn Eocene shells in the phosphate is due to its derivation in part from the residual soil. The presence of the rich marine Miocene fauna is accounted for by the submergence of the old surface during the Miocene. The vertebrate remains, which are Pliocene, Pleistocene, and Recent, are evidently later than the formation of the phosphate itself. According to this view, the black sandy clay which fills the cavities of the phosphate rock and in which many of the vertebrate remains are found, is also later than the phosphate. The originally irregular distribution of the phosphate, which was probably further increased by its later solution and reprecipitation, seems to explain the fact that the bed now varies greatly and rather abruptly in thickness. It also throws light on the fact that the phosphate bed is not generally thicker in the depressions of the old surface but appears to vary irregularly. The supposition that the Edisto as originally deposited was much thicker than the present phosphate bed is borne out by the fact that in the unaltered condition it is generally 4 or 5 feet thick, according to Sloan. The areas in which it is thus found were presumably islands in the old marsh where it was not subjected to the leaching and concentrating process, and the areas in which the Edisto was entirely lacking probably represent wave-swept islands in the estuaries in which the formation was deposited. This idea is partly borne out by the fact that the Edisto is lacking or is unphosphatized on the higher portions of the present interstream areas, as, for example, on that between Rantowles Creek and Edisto River and between the Ashĕpoo and the Combahee.

The experiments of Reese indicate that the leaching and concentrating process is possible, and that it has actually taken place is strongly suggested by the irregular shape of the phosphatized mass. Moreover, the Cooper marl immediately beneath the Edisto generally contains about 15 per cent of phosphate and for a distance of almost 30 feet commonly shows some enrichment. Below this the percentage of phosphate varies but seems to average about 3 per cent. The enrichment of the marl beneath the phosphate has been noted by several observers and is well shown in the first four analyses given below; the general composition of the marl at other, and probably lower, horizons is shown by the last six analyses.

Analyses of the Cooper marl.

	1	2	3	4	5	6	7	8	9	10
SiO_2 (and insoluble)		8.56	15.45	15.61	12.80	37.06	17.13	21.14	15.04	31.77
Al_2O_3		1.11	1.88	2.74	1.34	.83				11.75
Fe_2O_3		.95	.95	1.10	.79	1.38				
Na_2O					.35	.29				
K_2O					.32	.39				
MgO	0.65		.31	1.20	.43	3.91	Undet.	.56	Trace.	.45
CaO	29.44	48.80	43.41	41.80	45.68	26.80		33.76	43.52	39.80
SO_3	.58					.34				
P_2O_5	7.00	4.13	1.76	.45	1.29	3.03	3.01	1.26	10.65	2.98
CO_2	16.29	34.50	32.79	33.74	35.17	21.88	26.64	24.78	15.67	8.32
Ignition		.62	1.68	1.31	.91	1.65				1.80
Moisture		1.19	1.29	2.46	.96	2.07				.25
		99.86	99.52	100.41	100.04	99.63				
Equivalent $Ca_3(PO_4)_2$	15.28	9.02	3.85	.98	2.82	6.62	6.57	2.74	23.24	6.51
Equivalent $CaCO_3$	37.04	78.41	73.77	73.70	78.85	40.99	60.54	56.32	44.70	18.89

1. Marl immediately beneath phosphate bed; Bees Ferry, Ashley River. Sloan (op. cit., p. 385).
2. Marl 10 feet below phosphate bed; average sample; Ashley works, Ashley River. Sloan (op. cit., p. 384).
3. Marl 10 to 28 feet below phosphate bed; average sample; Ashley works, Ashley River. Sloan (idem).
4. Marl 28 to 50 feet below phosphate bed; average sample; Ashley works, Ashley River. Sloan (idem).
5. Average Cooper marl, exact horizon unknown; Steep Bluff, Biggin Creek. Sloan (op. cit., p. 386).
6. Average Cooper marl, exact horizon unknown; near Saxon, Goose Creek. Sloan (op. cit., p. 387).
7. Marl 34 feet below surface at Sineaths station. Chazal (op. cit., p. 26).
8. Marl 85 feet below surface at Sineaths station. Chazal (idem).
9. Marl containing phosphate nodules, 110 to 112 feet below surface at Sineaths station. Chazal (idem).
10. Average Cooper marl, exact horizon unknown; quarry at Woodstock (privately communicated).

Samples 1, 2, 3, and 4, taken at successively greater depths below the phosphate bed, show a gradual decrease in phosphoric acid. This would be expected from the experiments of Reese, which show that lime phosphate is precipitated slowly when in contact with lime carbonate. Owing to the moderate proportion of carbonate in the Edisto when it was first elevated above the sea and to the fact that this salt was constantly being removed by leaching and the proportion of phosphate thus increased, it is probable that phosphatic solutions were soon able to move freely in the mass. At first these solutions were weak because of the mass action of the carbonate present, and the phosphate was easily precipitated along the upper surface of the Cooper. With continuous decrease in the Edisto carbonate, however, the solutions increased in strength, were less easily precipitated, and finally penetrated some distance into the underlying Cooper before all of their phosphate was removed. The enrichment of the Cooper in phosphoric acid is well shown by analyses 1 and 2, of samples taken within 10 feet of the phosphate bed. Analyses 3 and 4, of samples taken between 10 and 50 feet below, show a decrease, 3 apparently representing about the original average composition of the marl, and 4 being abnormally low in phosphate.

The exact horizons of samples 5 and 6 are not known. They may represent the true average composition of the Cooper, but analysis 6, especially, shows a high proportion of phosphate, which is probably due to secondary enrichment. Samples 7, 8, and 9 were taken from the deep well at Sineaths station described above (p. 187); but their horizons are not stated by Shepard, and it is possible that sample 7 has undergone some enrichment. Sample 8 must be more than 50 feet below the phosphate bed, however, and probably represents the general average composition of the marl. Analysis 7 is of interest, as it shows the composition of one of the more highly phosphatic layers of the Cooper. The horizon of sample 10 is unknown, but as the phosphate bed is not present in the immediate locality from which it was taken the marl has probably not been directly enriched. It is difficult to ascertain the original average composition of the marl where not secondarily enriched, but it seems certain that it contains an average of at least 3 per cent of phosphate and is thus abundantly able to have contributed extensively to the formation of the Edisto.

The physical and chemical characters of the marsh and river deposits seem also to accord with the theory above outlined. The marsh deposits occur in a bed like the ordinary land deposits, but the rock is generally somewhat higher in specific gravity and is darker in color. As is generally the case, the darkest rock is commonly the richest in phosphate and the marsh deposits as a whole consist of high-grade rock. This is explained by the fact that it has been subjected to the action of swamp water longer than the land rock and that therefore the concentrating process has been longer continued. The result is a rock that is more compact and is richer in phosphate than much of the land rock. The darker color seems to be due chiefly to the inclusion of more carbonaceous matter during the longer period of association with swamp water. The color is therefore not directly connected with the phosphate content, but is nevertheless an indirect indication of it, for it is a rough measure of the length of time during which the concentrating process has gone on. Similarly the river deposits are darker and higher in specific gravity, although generally lower in phosphate, owing to the intermixture of sand. The rounded character of the fragments of river rock is doubtless due partly to the mechanical but chiefly to the solvent action of running water.

PHOSPHATE INDUSTRY.

PROSPECTING AND MINING METHODS.

Land mining.—Extensive prospecting and exploration work has been done in this area during the last 25 years, and it is reported that the location and extent of all of the workable deposits are known.

Much of this work has led only to outlining the deposits and gaining some idea of their thickness and the grade of the rock, but a great deal of detailed prospecting has also been done. Thus in the area shown on figure 55 (p. 198) one bore hole was sunk in each half-acre tract, or at intervals of less than 200 feet, and these were supplemented by a number of test pits. The information thus obtained affords a means of making a fairly accurate estimate of the quantity of minable phosphate in the ground in this area.

The greater part of the exploratory work has been done by boring with a long rod or auger or with a pipe. The auger used is an octagonal steel rod with a sharp point and a small shoulder just above the point. This rod is worked down through the unconsolidated sand and clay (see fig. 56) until it reaches the hard phosphate layer, when the distance traversed is measured. The rod is then forced through the phosphate layer into the soft marl below and is then withdrawn until the shoulder catches on the bottom of the hard layer. Another measurement is made, and the difference between the two gives the thickness of the phosphate. For more accurate work some operators use a 4½-inch pipe, which takes a core of rock that may be weighed or analyzed.

Mining is now done entirely by steam shovel, hand labor being impracticable where the overburden is thicker than about 8 feet. The tract to be mined is first thoroughly prospected, and in some tracts levels are run and drainage ditches are dug. Along one edge of the tract a canal about 20 feet wide and of sufficient depth to remove all the material above the phosphate is dug by a dredge or steam shovel. The dredge is, of course, preceded by a gang of laborers to clear the timber and blow out the stumps. The canal is extended in a straight line to the border of the property, the material removed being piled up on one bank and a movable steel track laid on the other. The phosphate layer is generally broken and dug with pick and shovel and thrown into buckets operated by a hoist that runs on the track and dumps the phosphate into flat cars. Some companies, however, remove the rock by a second steam shovel, of the clamshell type, which follows immediately behind the dredge. By the use of this second shovel the phosphate is broken up, hoisted, and loaded on cars in one motion, and hand labor is almost entirely dispensed with. It is said that one of these machines can load as many as 21 flat cars a day, although the average work of a machine is to load about 18 cars. Unless a system of lateral drainage ditches is developed one or two steam pumps are necessary to keep the canal dry, and these commonly follow the second shovel. When the border of the tract is reached the dredges are turned and a second canal immediately adjacent to the first is excavated, the overburden being thrown over into the old ditch. By this method practically all the phosphate is removed, and large areas that can not be mined by hand have thus been completely worked out. The marsh deposits are mined in a similar way, except that banks or levees are generally constructed to keep out water at high tide.

Hand mining can be practiced only where the overburden is less than 8 feet, and, as the more accessible deposits have been largely exhausted, very little hand work has been done during the last few years. Such work is generally performed on contract, the price being paid for the rock delivered at the washer. The contractor generally sublets to the laborer, assigning each man a section of about 18 feet along the sides of a common canal, from which he removes the overburden and digs and loads the phosphate.

River mining.—River mining was extensively practiced in the early days of the industry, but steadily declined after 1887 and practically ceased about 1904. (See p. 219.) The first river mining was done by hand in deposits that were nearly or quite uncovered at low tide. Shepard states that large quantities of rock were mined in this way, though the favorable deposits were few. In somewhat deeper water oyster tongs were used, especially on Wando River; and a small quantity of the rock was even dislodged and brought up by divers. The deposits in water sufficiently shallow for hand mining were soon exhausted, however, and steam dredges were introduced. The earliest models were adapted to working in water less than 20 feet deep, but with the exhaustion of the more accessible deposits the dredging was continued into deeper water until, according to Sloan, an extreme limit of 52 feet was reached. In most of this mining the clamshell type of dredge was used, but at least one large bucket dredge, carrying 38 buckets with a capacity of one-third ton each, was successfully used on Morgan River, where the rock occurred in a hard, compact layer. Much of the river rock occurs in more or less irregular banks, however, and some of the rock is probably overlooked. The tendency to dredge only the richest part of the deposit was strengthened by the practice of some of the companies of offering the dredge captain a bonus for a weekly production above a certain figure.[1] Most of the river mining was therefore very irregular and showed a marked contrast with the land mining, much of the river rock being lost.

PREPARATION OF THE ROCK.

After mining, the land rock must be washed and burned before it is shipped. As received from the dredge the phosphate is mixed with wet sand and mud derived partly from the overlying and underlying material, but chiefly from the stiff sandy clay which fills the cavities in the rock itself. It is reported that in the early days of the industry the rock was picked over by hand and scrubbed with a brush in some convenient creek and that the resultant product was so impure that the land rock acquired a bad reputation and was long regarded with disfavor.

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[1] Millar, C. C. H., op. cit., p. 162.

Hand washing was soon discarded as entirely inadequate and mechanical washers were introduced. At present the work is done almost entirely by machinery. The product is received on flat cars from the dredge and scraped off into a hopper that discharges into a mechanical conveyor. The conveyor buckets empty automatically into a crusher, where the rock is partly washed and is broken into fragments. It is then delivered through a trough to the lower end of a cylinder washer. This washer is a cylinder 27 feet long by 5 feet in diameter and is tilted so that the discharge end is a foot or more higher than the receiving end. The interior of the cylinder is fitted with plates arranged in the form of a spiral, so that as the cylinder revolves the phosphate is carried forward to the upper end. A stream of water under a pressure of 60 pounds enters the upper end of the cylinder and plays against the advancing phosphate, washing the finer material toward the lower end. This finer waste passes out through a heavy screen into a trough, through which it is carried by the water to the waste heap. The clean phosphate is discharged through the upper end of the cylinder onto a belt which transports it to the wet bins. While on the belt it is generally picked over by hand and any clay balls or fragments of marl are removed.

Much phosphate is lost in this grinding and washing. The operators estimate that 60 per cent of the material mined is sand, clay, and finely divided phosphate which escapes through the screens. Waggaman[1] says that an analysis of the material on the dumps showed about 13 per cent phosphate of lime, which is almost 8 per cent of the product as mined, or 20 per cent of the phosphate actually utilized. This may probably be taken as an average, though some phosphate deposits near Tenmile Hill are said by Chazal to be so friable and easily pulverized that a very large proportion is lost in handling and washing.

After washing, the rock is dried before being shipped in order to take advantage of the very material reduction in weight. In the early days of the industry the drying was accomplished by piling the rock in bins over perforated pipes carrying hot air, or in some places merely by exposure to the sun. The latter method was wholly inadequate and the former was only partly satisfactory, for 2 per cent or more of the moisture as well as most of the organic matter and carbon dioxide were still retained. Some operators, therefore, built expensive brickkilns in which the rock could be thoroughly calcined, but it was later found that these were unnecessary and that the rock could be satisfactorily burned over cordwood in open sheds. The present practice is, therefore, to pile the rock over ricks of cordwood, 6 cords being allowed for 100 tons of rock. The heat generated by the combustion of the wood is increased by that of the organic matter in the rock and also by the formation and combustion of water gas, so that the rock is popularly said to "burn itself." By this process the moisture content of the rock, which, after washing, is from 10 to 15 per cent, is reduced to about 0.5 per cent, and the organic matter and part of the carbon dioxide are also expelled. The burned rock is soft and easily ground and is light gray, yellow, or red.

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[1] Waggaman, W. H., op. cit., p. 9.

The river rock was purified in a somewhat different manner. According to Shepard, a lighter accompanied each dredge and all the washing was done before the material was taken ashore. The dredge emptied the rock directly into a conical washer, where it was cleaned by heavy streams of water. After leaving this conical washer the rock entered a crusher, through which it passed into a cylindrical washer for the final cleansing. This cylindrical washer discharged upon a second lighter on which the rock was towed ashore. The procedure varied somewhat according to the character of the rock and in many cases the first washing and the crushing were omitted. Owing to the more compact form of the river rock, many operators considered calcination unnecessary and dried it by hot air.

After the final drying the rock is shipped in closed cars—in former years it was shipped by vessel—to the fertilizer factories. After it has been calcined it is easily ground and is then mixed with sulphuric acid to produce an acid phosphate. The customary specification is 16 per cent soluble phosphate, although it is reported that a special method has been used to some extent by which a very high grade or double superphosphate is made. It is then generally mixed with calcined and finely ground marl, which acts as a base or filler and also as a drying agent, and with tankage, bone, potash, and ammonia salts, etc., in proportions which are varied according to the grade of fertilizer desired.

ECONOMIC FACTORS.

Workability.—In the South Carolina phosphate field, as in most other producing mineral fields, the gradually increasing cost of production has been met by the introduction of machinery and of improved methods of mining. Thus, in the early days of the industry, it was not considered practicable to remove an overburden of more than 6 feet on land or to dredge in water more than 15 feet deep. Yet in the last 10 years as much as 22 feet of overburden has been profitably removed, and river rock has been dredged from a depth of 52 feet, including a cover of 16 feet of sand and mud. It is thus difficult to define a workable deposit, especially at the present time, when the competition of the Florida and Tennessee rock prohibits the mining of deposits which 10 years ago were considered very favorable.

The most important factors are, of course, the thickness of the overburden and the thickness and compactness of the rock stratum. Under the conditions which have prevailed during the last decade 15 feet of overburden may be removed without excessive cost, but a greater thickness must be offset by an exceptionally high yield of phosphate. The amount of overburden that can profitably be removed also depends somewhat on the natural drainage of the property, for this affects the extent to which steam pumps must be used. The yield of the phosphate itself depends not only on the thickness of the stratum but also upon its compactness and its hardness. Other conditions being equal a 12-inch stratum is good, and a 10 or even an 8-inch stratum can be profitably worked. In some places, however, the cavities in the phosphate are exceptionally large and may reduce the yield of a 12-inch stratum below the workable limit. In some localities the rock is so soft and friable that it can not stand transportation and washing, for even the hardest rock generally suffers in the washing process. When the stratum is exceptionally thin its hardness may be very important, because the heavy dredge travels directly on it and must use it as a floor.

The composition of the rock is also important. The guaranty of lime phosphate has steadily risen from 55 per cent in 1880 (Shepard) to 60 per cent at the present day. This rise is not absolute, however, and has been largely met by improved methods of preparing the rock. Under the present method of calcining the rock nearly all of the moisture and organic matter and part of the carbon dioxide are eliminated, so that a rock which would have yielded 55 per cent under the old conditions of washing and air drying may now yield over 60 per cent. Even with this improvement in methods, however, the rock at many localities, especially along the northern and western borders of the fields, is too low in phosphate to be marketed under the present guaranty.

Cost of production.—Notwithstanding the extension of the workable deposits brought about by improved methods the industry has suffered seriously because of the increasing cost of production. The great increase in the price of labor and the exhaustion of the shallower deposits have practically put an end to hand mining. In consequence an elaborate and expensive plant is now necessary and the small operators have been forced out of the business.

Waggaman[1] estimates that under average conditions, when the plant is working to its full capacity, the cost per ton of mining, washing, and drying the rock is $3.46. The rainy seasons, which involve extra pumping, and the difficulty of obtaining labor, which frequently prevents the plant working to its full capacity, must also be taken into account. The present price, which is controlled largely by the higher-grade Florida product, is about $4 a ton. This leaves a very small margin of profit and in consequence mining operations have fallen off greatly.

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[1] Waggaman, W. H., loc. cit.

Grade of product.—The South Carolina rock is distinctly lower in phosphate content than the Florida product. (See p. 196.) The price of phosphate rock is fixed chiefly by the percentage of lime phosphate it contains, and the foreign trade generally specifies also a maximum percentage of iron and alumina. Before the exploitation of the high-grade Florida deposits the South Carolina river rock was very popular with the foreign trade, being fairly clean and low in iron and alumina. The appearance of the Florida rock on the market, however, injured and finally destroyed its export sale and for many years the South Carolina product has been sold only in the domestic market.

Although in this country the rock is priced largely according to its content of phosphate, certain factors seem to have aided the South Carolina product in competition with the higher-grade Florida rock. The fertilizer manufacturers find that after calcining it grinds readily and cheaply into an impalpable powder, which allows the sulphuric acid to act uniformly on the whole mass. The superphosphate formed is light and dries readily, and remains in good mechanical condition for mixing. Many planters, moreover, prefer fertilizer made from the South Carolina rock to that made from the Florida or Tennessee rock. There appears to be no chemical basis for this preference and it is probably due chiefly to the excellent physical condition of the South Carolina fertilizer.

HISTORY OF FIELD.

DISCOVERY.

It is interesting to note that the existence of the phosphate stratum was known long before its true nature and value were recognized. As far back as 1795[1] interest was attracted to the strata associated with the phosphate bed by the discovery in them of large numbers of teeth and bones. In 1837 F. S. Holmes collected a number of phosphate nodules from an old rice field on the west shore of Ashley River, but his interest was occasioned only by the fossil shells preserved in them. In 1842 Edmund Ruffin made a partial geologic survey of the State with special reference to marl and limestone for use as fertilizer; and in his description of the marl on Ashley River he mentions "lumps of stony hardness full of impressions of shells."[1] It is remarkable that he actually determined the percentage of lime carbonate in these rocks, but finding it to be only 6 per cent did not complete the analysis. In 1884 Holmes published a brief description of the fossiliferous rocks which he had found seven years before, describing them as a "remarkable bed of nodules or conglomerates 12 inches thick, embedded in clay";[2] and in 1860 again referred to them as a bed of silicified fragments of the underlying marl.[3] In 1848 Tuomey[4] described the nodules as "marl stones," from which the lime carbonate had been largely removed, leaving chiefly silica and alumina. Tuomey evidently relied on Ruffin's determination of these nodules, for although he presents numerous analyses of the underlying Eocene marl and points out especially the presence of phosphate in it, he gives no analysis showing the phosphate in the nodules.

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[1] Millar, C. C. H., op. cit., p. 125.

In a lecture delivered in 1859 before the Medical Association of South Carolina, C. U. Shepard referred vaguely to the presence of "phosphatic stone" near Charleston. Although he did not specify the rock in question, it appears from information quoted by Chazal[5] that he was acquainted with the true nature of the phosphate stratum and endeavored to organize a company to mine and utilize it as fertilizer. The Civil War put an end to these plans, however, and nothing definite was done until 1867, when St. Julian Ravenel made an apparently independent discovery of the nature of the rock. N. A. Pratt at about the same time recognized its value, and in company with F. S. Holmes immediately made an effort to organize a company. As a result of their efforts the Charleston Mining & Manufacturing Co. was formed in 1867 and a large area of excellent phosphate land on both sides of Ashley River near Tenmile Hill was secured. In the meantime Ravenel organized the first manufacturing concern, which was known as the Wando Fertilizer Co.

DEVELOPMENT.[6]

The first small cargoes of hard rock were shipped in April, 1868, but it was several years before adequate mining methods were developed and the work was properly organized. The first washer was built at Lambs in 1868, but until 1879 all of the product was shipped undried. Moreover, much of the early product was imperfectly washed and the land rock acquired a bad reputation, especially in the European market, which demanded a low percentage of iron and alumina. It was therefore practically excluded from the early foreign trade and has always found its best market in this country. The hot-air system of drying was begun in 1879 but was abandoned in 1882 for the present method of burning over cordwood. Up to 1888 mining was done almost entirely by hand, and steam shovels did not come into general use until about 1895. The Charleston Mining & Manufacturing Co., the pioneer concern, had a large working capital and acquired some of the best phosphate lands in the field. In 1868 this company built the first washing plant at Lambs and established headquarters there. It has always been the largest and one of the most prosperous companies, although it has had many competitors. Five companies were in the field in 1870, 16 companies in 1884, and 22 companies in 1891. Many of these, however, were small private enterprises and most of them have either ceased operations or have been absorbed by the Charleston Mining Co. In 1892 there was a change of management in this company, which resulted in the abandonment of the old plant at Lambs and the erection of a more costly one at Bees Ferry, a few miles farther down the Ashley. This apparently did not lead to the expected decrease in cost of production, however, and when the concern sold out to the Virginia-Carolina Chemical Co. in 1901 the new owners abandoned the Bees Ferry plant and returned to Lambs. In 1904 they completed a new plant which had a capacity of 1,200 tons a day and which was then the largest in the world.

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[1] Ruffin, Edmund, Agricultural survey of South Carolina, p. 35, Columbia, 1843.

[2] Holmes, F. S., South Carolina Agriculturist, 1844.

[3] Holmes, F. S., Post-Pleiocene fossils of South Carolina, p. ii, Charleston, 1860.

[4] Tuomey, Michael, Report on the geology of South Carolina, Columbia, 1848.

[5] Chazal, P. E., op. cit., p. 40.

[6] This account is taken in large part from the works of Chazal and Millar.

The river mining industry, dealing as it did with deposits in navigable streams under the jurisdiction of the State, early became involved in litigation, which hampered it for many years. Owing to the fact that expensive machinery was needed for the dredging, the operations were carried on by a few large companies, whereas the land mining was done by a number of small operators. In 1870 the general assembly of the State passed an act giving the Marine & River Phosphate Mining & Manufacturing Co. the right to mine phosphate rock from the navigable streams of the State for a term of 21 years, under a royalty of $1 a ton. This company, which began operations in 1870, immediately claimed exclusive rights and transferred exclusive rights to mine in Coosaw River to a new concern, the Coosaw Mining Co. The courts, however, later decided that no exclusive grant had been made and several other companies were formed. In 1876 another act was passed by which the Coosaw Mining Co. and all other concerns were granted exclusive rights within the territory in which their operations had been carried on prior to the passage of the act. By the close of 1878 ten river companies had been organized and six more were in process of organization. The Marine & River Phosphate Mining & Manufacturing Co.

ceased operations in 1882, but the Coosaw Mining Co., which had exclusive rights to the largest and highest-grade river deposits in the whole field, was extremely successful. By 1894 it had produced nearly half of the total amount of river rock mined and had paid the State about $1,500,000 in royalties. The original lease expired in 1891, however, and despite the claim that perpetual rights had been granted by the act of 1876, the State, after prolonged litigation, finally threw its territory open. During this litigation the company was forced to suspend operations and was unable to fill or renew its foreign contracts. Up to this time the rock from Coosaw River had enjoyed a high reputation in Europe, but when the supply was stopped the foreign consumers were forced to use Florida rock, which thus gained its first foothold and whose superiority became so apparent that the South Carolina rock was no longer preferred. The Coosaw Mining Co. resumed operations in 1892, but in 1893 a disastrous cyclone destroyed the plants of practically all the river companies and paralyzed the industry for some time. The richer deposits had by this time been exhausted, and the competition of the Florida, Tennessee, and Algiers phosphate had become keen; the cyclone therefore came at a particularly critical time and injured the river mining beyond hope of recovery. The industry rapidly declined during the next 10 years, and by 1904 all the large river companies had failed or ceased operations. Since 1904 a small amount of river rock has been intermittently mined, but the industry as a whole is practically dead.

In the following table is given the amount of South Carolina phosphate rock marketed in each year from 1867 to 1913.[1] The actual amount mined differs slightly from the amount marketed and is generally higher. The prices during this period have ranged from $10 to less than $3.50 a ton, depending partly on cost of production and partly on the market, which fluctuated considerably according to the condition of the crops. The prices paid for the river rock were generally about $1 lower than those paid for the land rock. In connection with the following table it may be noted that the Florida rock first appeared on the market about 1889 and that its production exceeded that of the South Carolina rock in 1894; and that the Tennessee rock first appeared about 1893, increased greatly in 1897, and exceeded the South Carolina rock in 1899. Until about 1885 South Carolina furnished over 95 per cent of the phosphate marketed in the United States; at present it furnishes 4 per cent or less.

---

[1] For statistics of production, prices, market, labor conditions, etc., in each year see U. S. Geol. Survey Mineral Resources, 1882-1913.

Production of marketed phosphate rock in South Carolina, 1867–1912, in long tons.[a]

Year.	Land rock.	River rock.	Total.	Year.	Land rock.	River rock.	Total.
ENDING MAY 31.				ENDING DEC. 31—Continued.			
1867	6	....	6				
1868	12,262	....	12,262	1890	353,757	110,241	463,998
1869	31,958	....	31,958	1891	344,978	130,528	475,506
1870	63,252	1,989	65,241	1892	243,653	150,575	394,228
1871	56,533	17,655	74,188	1893	308,435	194,129	502,564
1872	36,258	22,502	58,760	1894	307,305	142,808	450,108
1873	33,426	45,777	79,203	1895	270,560	161,415	431,975
1874	51,624	57,716	109,340	1896	267,072	135,351	402,423
1875	54,821	67,969	122,790	1897	267,380	90,900	358,280
1876	50,566	81,912	132,478	1898	298,610	101,274	399,884
1877	36,431	126,569	163,000	1899	223,949	132,701	356,650
1878	112,622	97,700	210,322	1900	266,186	62,987	329,173
1879	100,779	98,586	199,365	1901	225,189	95,992	321,181
1880	125,601	65,162	190,763	1902	245,243	68,122	313,365
1881	142,193	124,541	266,734	1903	233,540	25,000	258,540
1882	191,305	140,772	332,077	1904	258,806	12,000	270,806
1883	219,202	159,178	378,380	1905	234,676	35,549	270,225
1884	250,297	181,482	431,779	1906	190,180	33,495	223,675
1885	225,913	169,490	395,403	1907	228,354	28,867	257,221
				1908	192,263	33,232	225,495
ENDING DEC. 31.				1909	201,254	6,700	207,954
				1910	179,659	0	179,659
1885	149,400	128,389	277,789	1911	169,156	0	169,156
1886	253,484	177,065	430,549	1912	131,490	0	131,490
1887	261,658	218,900	480,558				
1888	290,689	157,878	448,567		8,721,518	4,105,195	12,826,713
1889	329,543	212,102	541,645				

[a] U. S. Geol. Survey Mineral Resources, 1892, p. 782, 1893.

PRESENT CONDITION.

As shown in the table, the production of the South Carolina field has fallen off greatly within the last few years and is now about equal to the production between 1875 and 1880. No river rock has been mined since 1910 and very little in the five years previous to that time. Land mining is confined chiefly to the Ashley district, but at the time of the writer's visit only one dredge was operating on the north side of the river and two on the south side. The Virginia-Carolina Chemical Co. is the principal producer, and only one other company is operating. The large washing plant at Lambs is the only one now in operation, although in the fall of 1913 three other plants were working, two on Stono River and one on Chisholms Island, near Beaufort. Under present conditions the price of rock is controlled largely by the Florida product, and the margin of profit in the South Carolina field is so small that mining is practicable only with the use of machinery capable of handling large quantities of material.

FUTURE OF THE FIELD.

The prospects of a marked revival of mining operations in this field are poor. The field attained its importance at a time when no other commercial deposits in this country were known and when, on the other hand, the widespread need of fertilizer was first being felt.

The increased cost of production, the exhaustion of the richer and more accessible deposits, and finally the extensive exploitation of the cheap and high-grade Tennessee and Florida deposits have proved a combination which the operators have not been able to withstand. The foreign trade has been completely lost, and under present conditions the rock can not be shipped out of the State.

It must be remembered, however, that there are probably at least 5,000,000 tons of 60 per cent phosphate still in the ground and that improved machinery may at some later time render these deposits workable. Furthermore, the South Carolina phosphate enjoys two advantages. First, the former importance of the field led to the building of a group of large fertilizer factories at Charleston, and the expense of shipping is therefore almost negligible; second, the rock makes an excellent superphosphate, and many planters prefer it to the higher-grade rock of the neighboring fields.

On the other hand, the highest grade rock that the field can be expected to produce does not average more than 61 per cent phosphate and generally exceeds 3 per cent iron and alumina. The cost of production is considerably higher than that in the Florida and Tennessee fields, so that the 70 per cent phosphate rock from those States can be delivered at Charleston at a price only slightly above that of the local product. This offsets the saving due to local manufacture, and the excellence of the superphosphate can scarcely compensate permanently for a difference of 10 per cent in phosphate content. The preference for the South Carolina rock is chiefly local, and although the demand within the State may continue for some time it probably can not affect the general phosphate industry.

It is probable, therefore, that only a small amount of mining will be done for some time. However, as the Florida and Tennessee deposits become exhausted prices may advance sufficiently to permit the profitable mining of the remaining South Carolina rock. On the other hand, the presence of great deposits of high-grade rock in Wyoming and Idaho points to an undiminished supply for many years and insures crushing competition in the interior part of the United States. All considerations, therefore, seem to indicate that the South Carolina field has passed its period of maximum production, and that despite the quantity and the favored location of the remaining deposits the field will not for a very long time be an important factor in the phosphate industry.

○

R D Crawford

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 580—K

ORE DEPOSITS IN THE SAWTOOTH QUADRANGLE BLAINE AND CUSTER COUNTIES, IDAHO

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BY

JOSEPH B. UMPLEBY

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1913, PART I—K

WASHINGTON
GOVERNMENT PRINTING OFFICE
1914

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

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ORE DEPOSITS IN THE SAWTOOTH QUADRANGLE, BLAINE AND CUSTER COUNTIES, IDAHO.

By Joseph B. Umpleby.

INTRODUCTION.

This report embodies the results of a rapid reconnaissance of the mining districts in the Sawtooth quadrangle, in Blaine and Custer counties, Idaho. The exceptionally rough topography, the wide distribution of the ore deposits over about 868 square miles, and the short period (12 days) available for the work made the data collected extremely fragmentary. As the information obtained is fuller than any that appears in the literature, however, it is desirable to place it on record. The principal sources of published information are scattered statements under the heading "Alturas County" in the reports of the Bureau of the Mint.[1] Later reports by the Director of the Mint do not contain information concerning the mines, and before the United States Geological Survey commenced to collect such information the principal mines of the region had ceased to be producers.

GEOGRAPHY.

The Sawtooth quadrangle is a high, mountainous area with summits at elevations of 9,500 to 10,000 feet above sea level and includes the divides between three large drainage basins. Its southwestern part is drained by the headwaters of Boise River, its east-central and southeastern parts by Wood River and its tributaries, and its northern part by Salmon River. (See fig. 57 and Pl. III.) The Sawtooth Mountains run sinuously across the quadrangle a little north of its center. From the Salmon River side they rise abruptly from a broad valley floor, 7,000 feet in elevation, to heights of 9,000 or 10,000 feet, and here and there a peak rises 1,000 feet higher. As seen from the north the crest is exceedingly serrate and bears a striking likeness to the teeth of a saw. As seen from the south, however, the summits blend with others of the highland areas and give the impression that they are parts of a dissected plateau. The Smoky Mountains constitute a poorly defined range which extends north and south across the central part of the quadrangle.

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[1] The production of the precious metals in the United States: Rept. Director of the Mint, 1881-1884, inclusive.

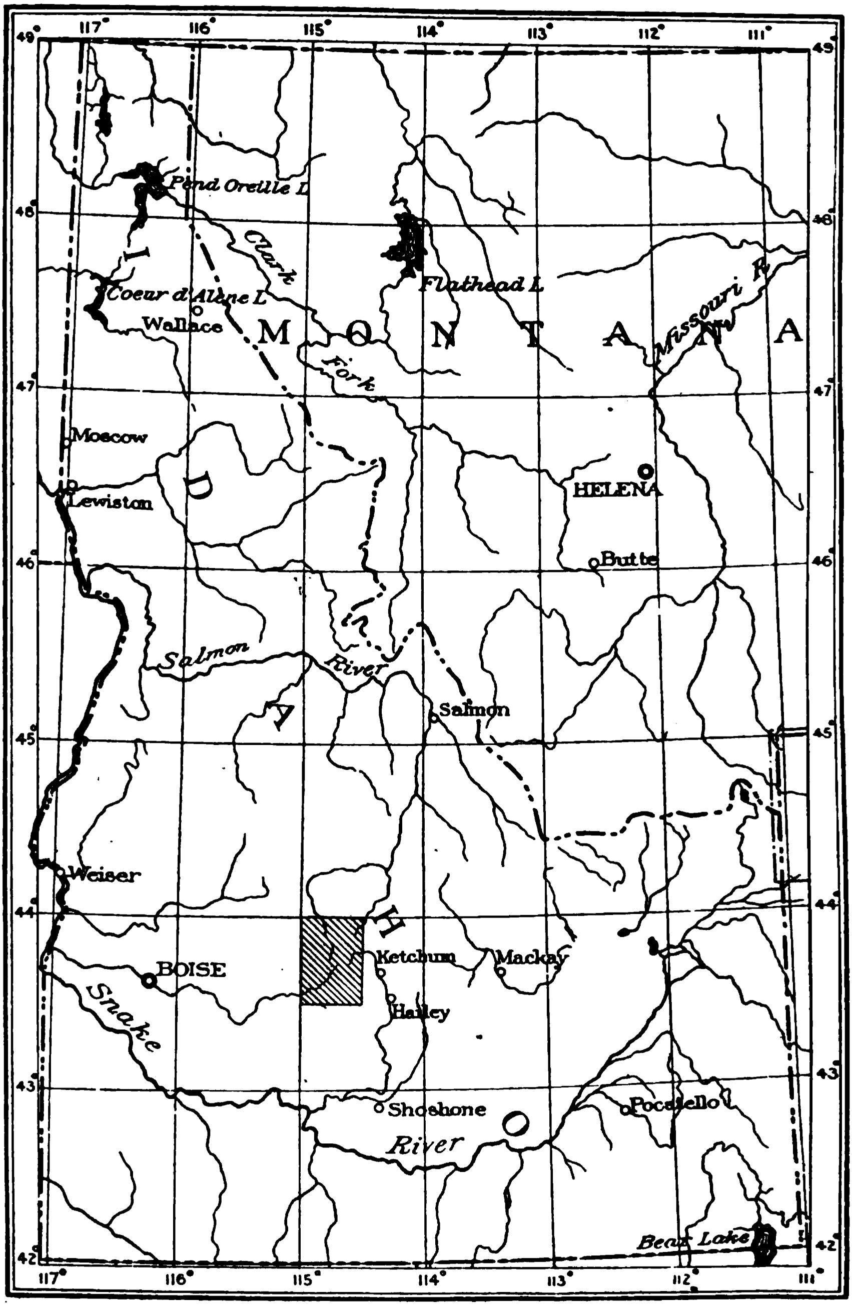

FIGURE 57.—Index map showing location of Sawtooth quadrangle, Idaho.

U. S. GEOLOGICAL SURVEY
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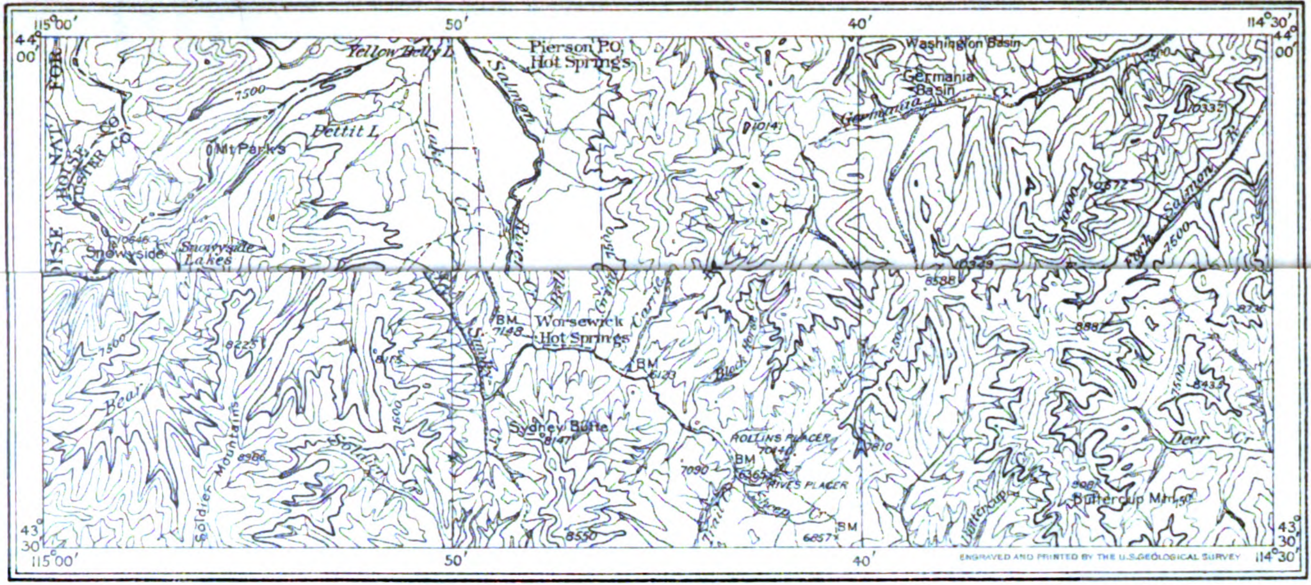
BULLETIN 580 PLATE III



Base from Sawtooth topographic sheet, U. S. Geological Survey, edition of 1900.

TOPOGRAPHIC MAP OF SAWTOOTH QUADRANGLE, IDAHO

Scale $\frac{1}{250,000}$

5 0 5 Miles

Contour interval 500 feet
Datum is mean sea level

The canyons of the area are typically deep, narrow gorges occupied by rapidly flowing streams, the beds of which range upward from a minimum level of 5,200 feet above sea. The only exception is the valley of Salmon River, which is broad and open for the first 8 or 10 miles within the quadrangle. West of it glaciers descending from the high Sawtooth Mountains have left terminal moraines at elevations near 7,000 feet, behind which the drainage is collected in beautiful lakes, which abound in fish and whose shores afford delightful camping grounds. Yellow Belly, Pettit, and Alturas lakes are thus situated. The streams that feed them flow from scores of smaller lakes situated in cirque basins high up in the mountains.

There are three hot springs in the quadrangle, one near its northern edge, another southwest of Carrietown, and the third on Wood River near the eastern edge. The springs deposit but little material, though the waters reach the surface with temperatures between 125° and 150° F.

Pierson, which is near the northern edge of the quadrangle, in the valley of Salmon River, is the only post office now in the area, and it receives mail but twice a week. In 1912 the industrial activity in the quadrangle comprised only the work of scattered groups of prospectors and miners, probably not more than 50 in all, and the grazing of large flocks of sheep during the summer months.

The area has few trails and fewer roads. Travel is exceedingly difficult in most parts of it, although bands of sheep roam over it widely. A trail up Boise River branches to the old mining camps of Vienna, Sawtooth, and Carrietown. Washington and Germania basins connect by trail with Clayton on the north and with Galena on the south. A wagon road branches north from the Hailey-Soldier stage road and leads to Carrietown, in the southern part of the quadrangle. Carrietown may also be reached by a road, now locally impassable, from Ketchum. A good road, which forms the main thoroughfare from Hailey and Ketchum to Pierson and Stanley Basin, crosses the northern part of the quadrangle along the valleys of Wood and Salmon rivers. It passes through the old smelter town of Galena, and branches from it lead to the now abandoned camps of Vienna and Sawtooth and to Germania Basin, Alturas Lake, and Pettit Lake, all within the drainage basin of Salmon River. A branch from it also leads up Boulder Creek canyon to the deposits in Boulder Basin.

HISTORY.

The earliest locations in the quadrangle were made in Boulder Basin in 1879 and on the east slope of Dollarhide Mountain in 1880, thus following closely the discovery of the rich silver-lead deposits near Hailey in 1878. During the three or four years following lode deposits were located in many parts of the area, and thriving mining centers sprang up near Carrietown, Boyle Mountain, Boulder Basin, Galena, Vienna, Sawtooth, and Germania Basin. The period of prosperity, however, was comparatively short, for in all the camps by 1890, and in most of the camps earlier, operations had almost ceased. The production during these few years can not be definitely ascertained, but fragmentary records and the statements of those who were connected with mining in the area indicate that it amounted to about $5,000,000, nearly all of it from silver-lead and silver ores. The deposits were rich in silver near the outcrop, shipments averaging several hundred ounces to the ton being not uncommon, particularly from the Sawtooth district. Concentrating mills were built in each of the districts, except Galena and Germania Basin, to handle the lower-grade ore. A 30-ton lead smelter was erected at Galena, but did not produce much bullion. A smelter at Ketchum handled a great deal of the ore; some was shipped to the smelter at Clayton, north of the area, and some was sent to reduction works farther away.

During recent years only the mill in Boulder Basin has been operated. The small amount of ore recently extracted from the other deposits has been mostly hand sorted and shipped to smelters in Utah.

PHYSIOGRAPHY.

The relief of the quadrangle ranges from 5,200 feet above sea level in the canyon of South Fork of Boise River to a little over 11,300 feet on the south wall of Boulder Basin. Common elevations, however, range from 7,000 feet in the canyons to 10,000 feet on the summits. The summits show a general accordance in level, which determines an undulating plain, which rises notably along the axis of the Sawtooth Mountains. This old erosion surface, well defined in areas farther northeast,[1] is not well preserved in this area and would scarcely be recognized were it not for the proximity of the other areas and its definiteness in them, but there can be little doubt that it extended over the Sawtooth quadrangle.

The relations of lava-filled valleys to uplands are the same here as elsewhere in east-central Idaho, the summits are of comparable height, the ridges and divides are similarly discordant in direction and distribution, and the relative resistance to erosion of different rock formations does not determine the elevation of the summits.

The physiographic history of this area, as interpreted largely in the light of the areas to the northeast, is legible for only the relatively small portion of geologic time that has elapsed since the late Mesozoic. Near the close of the Cretaceous period extensive regional elevation, thought to have been accompanied by the intrusion of the great granite mass which crops out over about half the quadrangle, rejuvenated the streams and began a period of erosion which by the close of the Eocene epoch had formed a far-reaching surface of slight relief.

---

[1] Umpleby, J. B., Some ore deposits of northwestern Custer County, Idaho: U. S. Geol. Survey Bull. 539, pp. 15-17, 1913.

This old surface now recorded by the summits of the area was raised to an elevation of nearly 10,000 feet at the close of the Eocene or early in the Oligocene, and the drainage ways again became channels of active erosion. During the Oligocene epoch the major streams, one of which flowed through the valley of the upper Salmon River and continued southward along the eastern side of the quadrangle to Camas Prairie, developed broad, deep valleys, which in the Miocene and possibly also in part of the Pliocene were the sites of lava flows and probably locally of lacustrine deposition.

The Pliocene, again, was a period of dominant erosion, in which the valley of Warm Springs Creek was cut to a depth of more than 2,000 feet into the Miocene lavas, and in the Pleistocene the upper ends of its branches were glaciated down to levels of 7,000 to 7,500 feet. During this epoch ice fields covered the uplands and the glaciers that occupied the higher portions of the valleys carved many of the features which now lend picturesqueness to the region.

GENERAL GEOLOGY.

SEDIMENTARY ROCKS.

Stratified rocks of probably Paleozoic age crop out in several parts of the quadrangle. (See Pl. IV.) The largest area is principally within the drainage basins of Germania and Pole creeks. Here the beds comprise fine-grained quartzite and dark-colored massive dolomitic limestone that grades upward into blue and white limestone beds and on into black slate, the slaty and quartzitic rocks being most abundant and apparently representing several thousand feet of beds. The sedimentary rocks also crop out in the vicinity of Boulder Basin, where a thick series of bluish and gray fine-grained quartzites and siliceous slates are exposed in the walls of Boulder Canyon. Another area of the Paleozoic beds extends from a point a few miles north of Boyle Mountain southward well beyond the quadrangle. Very little was seen of this area, but as the beds observed are similar in appearance to those in the vicinity of Hailey, a few miles to the east, it is believed that they represent the Wood River formation of Lindgren,[1] which is of Carboniferous age. The most abundant rock in the formation seems to be a reddish-gray and brown sandstone, in part calcareous. Perhaps second in importance is black calcareous shale, which apparently incloses beds of massive gray limestone. The remaining area of the Paleozoic rocks is in the vicinity of Carrietown. This seems to be a roof pendant of the granite mass which crops out on all sides except to the southeast, where the beds disappear beneath Tertiary eruptive rocks. The beds include limestone, magnesian limestone, slate, and quartzite.

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[1] Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, pp. 193-195, 1900.

Throughout all the areas the Paleozoic beds dip steeply, in most places away from north-south axes. Fossils were not discovered in them. They are not uniformly metamorphosed, and only locally along their contact with the granite do they contain secondary silicate minerals in quantity or size sufficient to be visible with a hand lens. At a few such places pyroxene, andalusite, epidote, and fibrous wollastonite and actinolite were detected.

Lacustrine deposits, probably of Miocene age, are believed to be present in the portion of the old valley which was not flooded with lavas. The presence of these deposits has not, however, been established, as the area believed to be occupied by them is now covered with recent alluvium and with a heavy mantle of outwash deposits, principally gravels, derived from the glaciers that occupied the adjacent uplands during the Pleistocene epoch.

IGNEOUS ROCKS.

GRANITE.

The central granite batholith of Idaho, one of the great intrusive masses of the North American continent, extends into the quadrangle from the west and comprises about two-thirds of its area. (See Pl. IV.) In most places its contact with the older sedimentary rocks is concealed by the broad belt of Tertiary lavas which follows the course of Salmon and Wood rivers to a point near the eastern border of the quadrangle and there turns south and joins the Snake River Plains in the vicinity of Camas Prairie. South of Boyle Mountain, however, a small mass of the granite crops out among Paleozoic rocks, and in the vicinity of Carrietown a small area of the sedimentary beds rises westward from beneath the lavas and is bordered on three sides by granite. Near the northern border of the quadrangle the granite and the sedimentary rocks are in contact for a few miles.

The granite area includes granite, quartz monzonite, and quartz diorite, each of the varieties resembling the others closely in megascopic appearance. The quartz diorite in general seems to contain more biotite and hornblende and is consequently somewhat darker, but its color is by no means a reliable distinguishing characteristic, for in places the granite is equally dark.

All the specimens from the vicinity of Carrietown are of quartz diorite. The rock is dark gray, equigranular, and made up of feldspar, quartz, biotite, and hornblende. Microscopic examination shows that the feldspars are oligoclase and andesine, no orthoclase being observed. Titanite, magnetite, and apatite are the principal accessory minerals.

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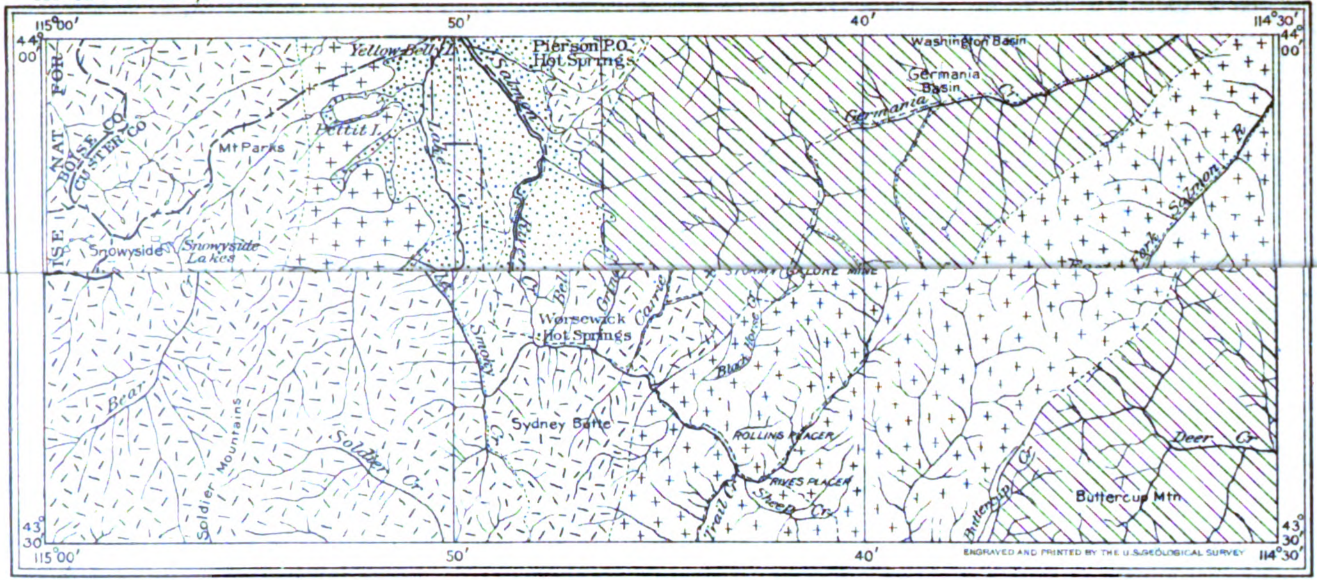
BULLETIN 580 PLATE IV



GEOLOGIC SKETCH MAP OF SAWTOOTH QUADRANGLE, IDAHO

By Joseph B. Umpleby

Scale $\frac{1}{250,000}$

5 0 5 Miles

1914

Base from Sawtooth topographic sheet, U. S. Geological Survey, edition of 1900.

LEGEND

SEDIMENTARY ROCKS

░	Recent alluvium and Pleistocene moraine and glacial outwash gravel	QUATERNARY
▨		

A specimen from near Boyle Mountain is a soda granite of dark-gray color and medium-grained texture, composed of feldspar, quartz, and biotite. In thin section the feldspars are seen to be orthoclase, notable amounts of albite, and a little oligoclase. In places the orthoclase and albite form microperthite. Apatite and zircon are the principal accessory minerals.

The rock inclosing the veins of the Vienna district is a light-gray medium-grained biotite granite, made up of orthoclase, microcline, a little albite, quartz, and biotite. Adjacent to the veins it contains much secondary pyrite, a little magnetite and chlorite after the biotite and sericite after the feldspars, and, in one section, epidote.

In Washington Basin quartz monzonite, characterized by a marked phenocrystic development of the feldspars, is exposed over a small area. This rock is gray and is made up of large crystals of orthoclase set in a groundmass of medium-grained feldspar, quartz, and biotite. The groundmass is packed with micropegmatite, which also occurs in zones surrounding orthoclase crystals. Plagioclase, mostly oligoclase, is somewhat less than orthoclase in amount and much of it shows marked zonal growths. Near the ore deposits the quartz monzonite becomes greenish gray in color and has a silky luster. It grades through zones in which patches of secondary pyrite and sphalerite occur in chloritized quartz monzonite into ledge matter made up of arsenopyrite, pyrrhotite, quartz, sphalerite, and pyrite, in which the original granite can be identified only locally.

DIKE ROCKS.

Dike rocks occur in several parts of the quadrangle, but only in Boulder Basin were they observed to be particularly numerous. They comprise perhaps one-third of the rock exposed in the basin and present a wide range in composition and in size, individual intrusions ranging from a few inches to a few hundred feet in width. The study of their relations and differences was too hurried to permit detailed descriptions, but granite porphyry, quartz monzonite porphyry, diorite, and a rare lamprophyre, spessartite, were identified.

The granite porphyry is steel gray and is made up of phenocrysts of feldspar and a little hornblende, closely spaced in a fine-grained groundmass. Orthoclase exceeds albite in amount, hornblende is abundant both in the groundmass and as phenocrysts, and quartz is confined almost entirely to the groundmass.

Quartz monzonite porphyry traverses the vein in Golden Glow tunnel No. 2. It is a light-gray rock with phenocrysts of feldspar and a little quartz, biotite, and hornblende set in a fine-grained groundmass. The feldspars include oligoclase and orthoclase in about equal amounts. In the specimen studied the biotite and hornblende are largely altered to epidote, chlorite, and magnetite, and sericite is developed after some of the feldspars.

Diorite porphyry, a greenish-gray rock with numerous medium-sized phenocrysts of feldspar, occurs near the mouth of Golden Glow tunnel No. 2. Plagioclase, of about the composition oligoclase-andesine, greatly exceeds biotite in amount. Secondary minerals in the specimen are epidote, after the biotite and some of the feldspar, and sericite, after the feldspar. Pyrite also is present.

The specimen of spessartite was obtained near the face of Golden Glow tunnel No. 2 and is a dark-colored rock with phenocrysts of hornblende and sparsely scattered biotite in a holocrystalline groundmass. The hornblende occurs in two distinct generations and about equals the oligoclase in quantity. One large grain of quartz and three small grains of pyrite occur in the section. The groundmass is an aggregate of interlocking feldspar and hornblende crystals.

In the vicinity of Carrietown diorite porphyry, monzonite porphyry, and granite porphyry dikes were observed along the ridge north of Dollarhide Mountain, where they traverse both the quartz diorite and the Paleozoic sedimentary rocks. They are similar in appearance and mineralogy to those above described from Boulder Basin.

TERTIARY ERUPTIVE ROCKS.

Tertiary lava rocks and related tuffs form a wide belt that follows the valleys of Salmon and Wood rivers to the eastern border of the quadrangle and there turns south-southwest and leaves the area between Buttercup Mountain and Sydney Butte. A branch leads northeastward in the vicinity of Galena and another eastward along Wood River. Except within the drainage of Salmon River they fill an old erosion valley, the bed of which is nowhere exposed within the area. The contact of the lavas with the older rocks was seen only in places where the boundary is indicated on the map by solid lines, but as the areas of these rocks contrast sharply in color with the light gray of the granite soil, it is believed that their general distribution is about as indicated. Warm Springs Creek traverses the lava belt between Boyle Mountain and Dollarhide Mountain. Its canyon is from 2,000 to 3,000 feet deep, but in no place has it cut through the eruptive rocks. Within this drainage basin andesite predominates, but on the upper slopes there is considerable rhyolite and some poorly bedded rhyolitic tuffs.

The lavas are believed to occupy an old erosion valley, because much of the basin in which they occur lies athwart the structure axes of the region, and because there is no evidence of faulting in any of the several exposures observed along the sides of the basin. In places along their margins the basal lavas have picked up vast quantities of fragmental material from the underlying beds, as near the mouth of Thompson Creek; elsewhere, as on the east slope of Dollarhide Mountain, they rest against a surface of weathered granite. Except in the extreme northern part of the belt the lavas essentially fill the old valley, and in the vicinity of Easly and Galena peaks they rise somewhat higher than the general upland level. Within the Salmon River drainage area much of the old valley was probably never filled with lava rock, for if it was it seems impossible to account for the broad valley, which is now so strikingly discordant with the other topographic features of the region. This discordance is particularly emphasized by the deep, narrow canyon, cut in rocks of similar composition and structure, which is entered by Salmon River about 25 miles north of the quadrangle. It is not unlikely that lacustrine deposits underlie this portion of the old valley, for there seems to have been no outlet from the basin until the Salmon River canyon was excavated, and this must have required a very long time. It is not impossible that the waters draining into the basin escaped southward beneath the lavas along the old channel, but there is no specific evidence in support of this idea. If a lake existed in this basin rock waste from the high mountains adjacent certainly accumulated in it as lacustrine deposits, and if no lake existed subaerial deposits as certainly formed. These older beds, believed to be present, are now well concealed by a heavy mantle of outwash derived from the glaciers which occupied the adjacent uplands during the Pleistocene epoch and by alluvium of more recent origin.

The lava rock comprises principally andesite and rhyolite, but experience elsewhere in the same general series suggests that many of the andesites as determined microscopically would prove on chemical analysis to be latites.[1] Associated with the lavas are their related tuffs, but these were not observed to be abundant anywhere within the quadrangle. The andesites are greenish, purplish, lavender, or gray; some contain important amounts of biotite, others considerable quantities of hornblende, and in a few specimens augite is conspicuous. In them the phenocrysts and groundmass are about equal in area. The feldspars in different specimens range in composition from $Ab_{70}An_{30}$ to $Ab_{55}An_{45}$, or from a calcic oligoclase to a calcic andesine. The groundmass in most of the thin sections is cryptocrystalline to glassy. Rhyolite was observed as a light-gray rock along the upper slopes of the valley of Warm Springs Creek. Orthoclase quartz and rarely sanidine appear as scattered phenocrysts in a cryptocrystalline groundmass which shows distinct flow structure and is made up of microlites of feldspar which in many places give way to glass.

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[1] Umpleby, J. B., U. S. Geol. Survey Bull. 528, pp. 47–48, 1913, and Bull. 539, pp. 25–26, 1913.

ORE DEPOSITS.

CHARACTER AND DISTRIBUTION.

The principal ore deposits found in the Sawtooth quadrangle are fissure veins and replacements along shear zones. Only one epoch of mineralization is recognized, and this followed the intrusion of the granite batholith in late Cretaceous or early Eocene time and preceded the filling of the old valley, which, as indicated in areas farther north, probably took place principally during the Miocene epoch.[1] The veins may be grouped according to the leading metal contained, as silver-lead, silver, zinc, and gold deposits, and they will be described in the order named. Of the production of perhaps $5,000,000 credited to the quadrangle, nearly all has come from the first two groups of deposits. The zinc ores have yielded $40,000 or $50,000, but the gold veins have not been exploited to economic advantage.

The known deposits occur in the southern, eastern, and northern parts of the quadrangle. Nearly all were staked out and exploited within five years after the discovery of the rich silver-lead deposits near Hailey in 1879. Even the gold veins of Washington Basin were known to the early prospectors, who spread into the surrounding country from the camps of Vienna and Sawtooth, but not until 1894 were claims staked to cover them.

SILVER-LEAD DEPOSITS.

Argentiferous galena deposits occur in all the districts in the quadrangle, though ores of this type afforded but a small part of the production from the mines near Sawtooth and Vienna. The veins are typical fissure fillings and replacements along sheared zones and are distinctly tabular in outline. Siderite and quartz are the characteristic gangue minerals. Sphalerite, tetrahedrite, and locally arsenopyrite and pyrrhotite are associated with the galena in most of the veins. The veins traverse the Paleozoic beds near Carrietown, Boyle Mountain, and in Boulder, Germania, and Washington basins. At Vienna and Sawtooth they are inclosed in biotite granite, and in the vicinity of Boyle Mountain some of them extend from the area of Paleozoic rocks across the igneous contact into the soda granite.

The amount of silver in the ores varies from place to place, even in the same district. Thus the Silver Star ore contained 15 to 16 ounces of silver to the ton, and the Isabella, less than a mile away, averaged from 200 to 400 ounces. Shipments from different shoots in the Golden Glow mine contained widely different amounts of silver, the range being from 56 to 360 ounces to the ton. The silver content of the ore is not invariably related to its content of lead; where it is particularly high it seems to be concomitant with the presence of gray copper. In the Boulder Basin and Sawtooth districts gold accompanies the lead in noteworthy amounts. The Golden Glow ores as now worked contain 0.32 to 0.63 ounce of gold to the ton and assays of the Mountain King ores give returns of 0.58 ounce to 1.58 ounces of gold. Elsewhere in the quadrangle gold occurs in the silver-lead ores but in less amount than in these districts.

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[1] Umpleby, J. B., loc. cit.

SILVER DEPOSITS.

It is impossible to draw a sharp line of demarcation between the silver and the silver-lead deposits. Many of the mines were worked primarily for silver but at the same time produced considerable amounts of lead. Others were worked exclusively for silver, the small amount of lead in the ore being lost in the metallurgic process used. Only deposits that were worked for silver alone are here discussed, and these include the veins of the Sawtooth and the Vienna districts. The Mountain King mine, in the Vienna district, however, has recently been worked for lead-silver ores which were left in the mine during the early period of activity, when only silver and gold were recovered.

The silver-bearing veins occur well within the main granite mass and are extensively developed by tunnels, few of which are now accessible. The veins range from a few inches to 15 feet in width and are characteristically quartz fillings containing tetrahedrite, proustite, and silver-bearing galena and sphalerite. Some of the ores are said to have contained as much as 4,000 ounces of silver to the ton, but the average was probably less than 75 ounces. Only the Mountain King mine (see p. 248) was accessible at the time of visit.

ZINC DEPOSITS.

Deposits of zinc occur in the Lucky Boy mine, which is on the east side of Rooks Canyon, southeast of Boyle Mountain. This mine has produced about 2,600 tons of 45 per cent zinc ore from veins worked intermittently for several years. The mine was not visited during the reconnaissance, but specimens of the ore consist of sphalerite, pyrite, and a little galena and arsenopyrite in a quartz-siderite gangue.

GOLD VEINS.

Large low-grade gold veins, entirely different in character from any other of the deposits, occur in Washington Basin about half a mile north of the quadrangle. Here five ledges from 6 to 72 feet in width cross a low ridge which divides a large cirque into two basins. All the veins are inclosed in porphyritic quartz monzonite, which at many localities is clearly replaced by the vein material. Three of the veins have been opened in several places by short tunnels, pits, and open cuts, and each opening reveals quartz which is either honeycombed and iron-stained or is heavily impregnated with pyrrhotite, pyrite, or arsenopyrite. The principal vein is called the

Empire and averages about 30 feet in width through an extent of four claims. Near the surface this vein is intensely oxidized, but at a depth of a few feet primary minerals appear. Arsenopyrite, sphalerite, and galena occur as small patches, but near its southern end pyrrhotite and about an equal amount of intermixed quartz and diopside form a band, 15 to 20 feet wide, next to the hanging wall. The pyrrhotite clearly replaces the quartz monzonite, the quartz of which remains. The feldspar and biotite crystals are completely transformed to pyrrhotite and diopside. Farther north on the Empire vein sphalerite occurs with small amounts of pyrite, stibnite, pyrrhotite, and arsenopyrite.

The granite adjacent to the vein is intensely sericitized and locally is greenish gray and has a silky luster. It passes through a zone in which patches of pyrite and sphalerite occur in chloritized and sericitized quartz monzonite into ledge matter made up of sulphide minerals, pyroxene, and quartz, in which the original quartz monzonite is only locally and imperfectly preserved.

The tenor of these veins is not known, but that they contain some gold was proved by panning the specimens collected. In the section on Germania and Washington basins (pp. 244–246) appears additional information concerning them.

SUPERFICIAL DEPOSITS.

Gold placers that occur along the upper valley of Little Smoky Creek have been worked intermittently in a small way for a number of years. They were not examined during the reconnaissance.

MINERALOGY OF THE ORES.

The mineralogy of the ores of the Sawtooth quadrangle is comparatively simple. The more abundant minerals in the lead-silver and silver deposits are argentiferous galena and sphalerite, tetrahedrite, proustite, pyrite, chalcopyrite, and locally arsenopyrite, and pyrrhotite in a quartz-siderite gangue. In the gold-bearing veins the characteristic minerals are pyrrhotite, arsenopyrite, and pyrite, along with a little sphalerite, galena, stibnite, and chalcopyrite in a quartz gangue in which diopside is locally abundant.

Oxidation in few places extends more than 100 feet below the surface, and in most of the deposits primary ore occurs within a depth of 50 feet. The common alteration products are lead carbonate, cerargyrite, iron and manganese oxides, copper carbonates, smithsonite, and calamine.

ALTERATION OF THE WALL ROCK.

Alteration seems to be more pronounced in the igneous than in the sedimentary wall rock. Specimens of granite taken near the ore bodies in the Vienna district are packed with sericite that developed after the feldspars and locally after the biotite and with chlorite and epidote that developed after the biotite. In Washington Basin much of the vein material is clearly replaced quartz monzonite, it being possible to obtain specimens showing every gradation from material composed principally of quartz, pyrrhotite, sphalerite, and arsenopyrite or quartz, pyrrhotite, and diopside to quartz monzonite containing isolated patches of secondary pyrite and sphalerite in chloritized and sericitized quartz monzonite.

In view of the intense metasomatic replacement and the diopsidization of the quartz monzonite in the deposits of Washington Basin, it is perhaps surprising that no contact metamorphic replacement deposits have been found. All the veins in Washington Basin, however, are within the area of the igneous rock, and it is possible that overlying contact deposits have been swept away by the erosion which formed the basin.

AGE OF THE DEPOSITS.

The deposits of the quadrangle are believed to represent one general epoch of mineralization, which was closely related to that of the intrusion of the Idaho batholith. At Vienna, Sawtooth, and in Washington Basin the ores are inclosed in the igneous mass; elsewhere they are in sedimentary rocks not far removed from the igneous contact. In Boulder Basin and in the vicinity of Carrietown dikes of granite porphyry and diorite porphyry traverse the veins. These dikes are very different in appearance from those that accompanied the Miocene lavas and quite certainly are differentiates from the batholithic magma. The ore solutions therefore are believed to have escaped from the batholithic mass before it had completely solidified. The granite of the batholith is believed to be of late Cretaceous or early Eocene age, and hence the veins belong to the pre-Oligocene deposits recognized elsewhere in the State.[1] The late Tertiary epoch of mineralization is not known to be represented in the quadrangle.

MINING DISTRICTS OF THE SAWTOOTH QUADRANGLE.

ROSETTA DISTRICT.

GENERAL FEATURES.

The Rosetta district, sometimes included in the Little Smoky district, embraces an unorganized area of perhaps 100 square miles in the vicinity of Carrietown in the southern part of the quadrangle. Dollarhide Mountain is the principal landmark in the vicinity, though it is but little higher than many other summits in the region. A wagon road, about half a mile of which was impassable for vehicles in 1912, leads 22 miles east to Ketchum. Except for the Dollarhide summit this road has an easy grade, and it might be put in excellent condition by an expenditure of a few thousand dollars. The highway from Carrietown now in use follows down Carrie Leonard Creek and thence east over Sheep Creek summit and joins the main stage road between Hailey and Soldier. The 4 or 5 miles of this road below Carrietown is along the creek bed and washes badly during the spring freshets.

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[1] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, pp. 26, 62, 68, 1913.

HISTORY AND PRODUCTION.

The principal mineral locations were made in 1881 and 1882, and for a score or more of years thereafter the Rosetta district was one of the active mining centers in Idaho. Five concentrating mills were in operation part of the time and much of the better grade of ore was packed and later hauled to the smelter at Ketchum. During recent years, however, the district has been comparatively inactive and efforts to recover in depth the veins which were exceptionally productive near the surface have met with indifferent success. None of the mills have been operated for several years and most of them are partly dismantled. The principal activity in 1912 was directed toward locating at a depth of 280 feet the Carrie Leonard veins, which are locally reported to have produced approximately $500,000 from above the 150-foot level. This work was continued during 1913 and served to indicate that the argentiferous galena gives way to sphalerite, pyrite, and arsenopyrite in depth.

The total production of the district does not appear in official records and can be approximated only from the output of individual mines as reported by residents of the vicinity. The Carrie Leonard, said to have yielded $500,000, holds the highest record of production. Then follows the King of the West with $200,000, the Stormy Galore and Tyrannus with $100,000 each, the Dollarhide and Silver Star with about $75,000 each, the Margaret with $30,000, the Isabella with possibly $20,000, and the Sunday with perhaps $15,000. In all, the district has produced perhaps $1,000,000.

TOPOGRAPHY.

The Rosetta district is a high, mountainous area, which ranges in elevation from 5,500 to 9,000 feet. The western part is drained by tributaries of Big and Little Smoky creeks, which flow westward into West Fork of Boise River. The eastern part is drained by Warm Springs Creek, a tributary of Wood River. The area has a wide range in climate. In summer it is a beautiful park, in which a dense forest of fir and pine rises above a fairly open undergrowth, but in winter it is a desolate expanse of snow, traveled by men only on skees and webs. The open season includes the months from May to November.

GEOLOGY.

The rock formations of the district include a small area of Paleozoic sedimentary rocks, bordered on the southeast by Tertiary lavas and on the other sides by the great granite batholith of Idaho, which extends westward and northward for several hundred miles. The sedimentary rocks include limestone, magnesian limestone, slate, and quartzite and dip 20° to 50° E. Dikes of diorite and monzonite porphyry traverse both the granite and the Paleozoic rocks. They are well exposed on the ridge north of Dollarhide Mountain but occur also in several of the mines. (See p. 228.)

Perhaps the most noteworthy feature of the geologic relations of this district is the absence of important contact metamorphism, even in the limestone areas. The microscope reveals a little diopside and a few shreds of wollastonite and termolite, but in no exposures seen were metamorphic minerals visible with a hand lens. This contrasts markedly with the observations of Lindgren on the contacts of the Hailey area to the east[1] but agrees well with the general observation that metamorphic minerals are not uniformly developed around intrusive masses even when in contact with rocks that are similar in composition and structural features.

ORE DEPOSITS.

The ore deposits of the district occur as veins and tabular replacements, containing principally argentiferous galena, tetrahedrite, and sphalerite in a quartz-siderite gangue. Pyrite, chalcopyrite, and a little arsenopyrite are present in many of the ores. Most of the veins occur along crushed zones, and large quantities of fragmental wall rock are included in the gangue. The common strike of the veins is northeast-southwest, with dip either to the northwest or to the southeast, in most places at angles greater than 45°. There is little evidence of hydrothermal alteration, but replacement phenomena are plentifully illustrated. Bunches and stringers of ore protrude into the wall rock in many places, and the veins are markedly different in width within very short distances.

The ores mined were of excellent grade and were valuable chiefly for their silver content, which in different veins ranges from 17 to 400 ounces to the ton, the principal production having been derived from ores averaging 100 to 200 ounces.

Oxidation is confined to a narrow zone near the surface and in none of the deposits is it complete to a depth greater than 50 feet. The outcrops of the ledges are characterized by iron-stained quartz, coarsely honeycombed, with widely spaced cavities of unequal size and irregular shape. Within a few feet and in places within a few inches of the surface, however, the quartz becomes solid and primary sulphide minerals appear. Galena occurs nearer to the surface than any of the other sulphide minerals, and most specimens of surface ore contain fragments of it. Recent developments on the Dollarhide and Carrie Leonard veins indicate that galena decreases and sphalerite increases markedly in depth.

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[1] Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: U. S. Geol. Survey, Twentieth Ann. Rept., p. 195, 1900.

The age and genesis of the deposits have already been discussed (p. 233), but note may be made here of the dike of diorite porphyry that traverses the vein in the Dollarhide mine. This dike is almost certainly a differentiate from the granite magma. Elsewhere in the vicinity veins traverse the granite. This seems to show that the ore solutions escaped from the magma before its solidification was complete.

MINES AND PRINCIPAL PROSPECTS.

Carrie Leonard mine.—The Carrie Leonard group, comprising eight patented claims, occupies the lower end of the sharp ridge between the two branches of Carrie Leonard Creek at Carrietown. The present working tunnel enters the hill from the northwest at a point near the creek level about 200 yards above the town. Other developments include three tunnels from the north and an equal number from the south. A 40-ton concentrating mill, formerly equipped with wilfleys and jigs but now dismantled, is situated on the south side of the ridge.

Two veins, both inclosed in hard black, locally calcareous quartzite, have been worked and have yielded about $500,000. One of the veins strikes N. 40° E. and dips 40° SE.; the other strikes N. 55° E. and dips 58° SE. They cross within the claim, and the best ore has been found by following down along their intersection, where the ore is said to have averaged 30 per cent lead, 5 to 6 per cent zinc, and 150 ounces of silver to the ton. This grade of ore extended southward from the intersection for 100 feet along one vein and for about 70 feet along the other, and it continued to a vertical depth of 160 feet, or 650 feet down the line of intersection. Below this point, which is 130 feet above the level of the gulch, little ore has been found. Although the vein here is persistent and the gangue is similar to that above, galena seems to have given way to sphalerite. The bottoms of the old stopes were inaccessible in most places at the time of visit, but in every place observed the ore shoots seemed to pinch out. A strong fault transverse to the course of the vein is exposed in tunnel No. 2, but as it crosses at a point 70 feet beyond the end of the shoot its bearing on the continuation of the ore is of doubtful significance.

Dollarhide mine.—The Dollarhide group comprises 17 claims on the divide between Carrie Leonard and Warm Springs creeks. At the point where the road crosses this divide it is 8,719 feet above the sea. To the east and to the west the claims extend down the slopes to an elevation of about 8,000 feet, and to the north, near the principal workings, the ridge rises to 9,200 feet. East of the divide is a partly dismantled 40-ton concentrating mill.

The developments include 3,000 feet of work in four tunnels about 100 feet apart. The upper two are no longer accessible and the lowest has not been carried to the vein. Tunnel No. 3 is the principal level and may be entered through either of two portals, which are 535 feet apart. The southern portal is the end of a 120-foot crosscut, which extends westward to the surface from a point on the vein about midway between the north portal and the face of the workings.

The vein, which is inclosed in massive limestone, some of it very siliceous, strikes N. 50°–60° W. and dips 60° SW. in the eastern part of the mine and 70° NE. in the western part, the dips being opposite on opposite sides of a diorite porphyry dike which crosses tunnel No. 3 about halfway between the two portals. Near the northern adit of tunnel No. 3 it is crossed by a fault which strikes N. 10° E. and dips 28° SE. Ore has not been found west of it. Faults also cross the ore body in the eastern end of the workings, one of them causing an offset of 10 feet to the north on the east side and another an offset of 80 feet in the same direction.

The vein is 3 to 6 feet wide and consists of quartz, through which sphalerite and galena are scattered, and of crushed wall rock in about equal amounts. The better grade of ore occurs as ill-defined lenses that are greatly elongated nearly parallel to the strike of the vein. One of these lenses lies between levels Nos. 2 and 3, but extends down to No. 3 only in a few places.

Isabella mine.—The Isabella, comprising one patented claim, lies between the Carrie Leonard and Dollarhide groups. The developments consist of three short tunnels and a 50-foot shaft, all inaccessible at the time of the examination. The mine was discovered in 1881 and was operated by lessees for a number of years. The ore is said to have been of excellent grade, some of it containing as high as 400 ounces of silver to the ton along with lead and a little zinc. The mine is credited with a production of $25,000.

Margaret mine.—The Margaret claim, situated east of the Dollarhide group, at an elevation of 8,200 feet, back of the Dollarhide mill, was discovered in 1880 and is the oldest location in the vicinity of Carrietown. It produced $32,000 from highly argentiferous lead ore. The developments include about 1,500 feet of drifts and tunnels, no longer accessible. The ore body occurred as a horizontal lens in a steeply dipping crushed zone which traverses siliceous limestone beds. Other ore bodies have not been found.

Silver Star mine.—The Silver Star mine is situated about a mile southwest of Carrietown at an elevation of 7,700 feet. It is well within the area of sedimentary rocks that comprises the productive portion of the district. The mine has not been operated since 1888 and most of the workings are now inaccessible. The property includes 10 to 12 patented claims and a 20-stamp concentrating mill, which after running 20 days was in part dismantled because the amount of silver in the ore fell far below expectations. The ore is said to average 15 or 16 ounces to the ton in silver and about 4 per cent lead with an equal or greater amount of zinc. The developments include an incline 270 feet deep with drifts at vertical depths of 105, 155, and 205 feet below the collar. The lowest level, No. 3, connects with the surface by a crosscut tunnel and a prospect winze follows the ledge to a farther depth of 200 feet. The drifts on the vein aggregate about 2,500 feet in length and explore the ledge for 300 feet west of the shaft on levels Nos. 1 and 3 and for 700 feet east of the shaft on levels Nos. 2 and 3. Very little stoping has been done, the production of $75,000 and the 15,000 tons of ore now on the dumps being reported to have come from the development work. It is said that breasts of ore up to 12 feet wide occur at many places in the mine and that the principal shoot is 400 feet long.

The ledge, which is inclosed in thin-bedded dark-gray siliceous limestone, strikes almost east and west and dips 40°–45° S. at the outcrop, gradually straightening to nearly vertical at the bottom of the 200-foot winze. The ore as seen on the dump consists of intimately associated tetrahedrite, sphalerite, galena, pyrite, and chalcopyrite in a medium-grained quartz-siderite gangue. The outcrop of the ore body is a honeycombed iron-stained quartz through which galena and anglesite are sparsely distributed.

Silver Crown mine.—The Silver Crown mine, formerly the Climax, is situated near the crest of the ridge one-half mile west of the Silver Star. Two tunnels, one 500 and the other 200 feet long, enter the hill from the north, and a third, 300 feet long, enters from the south. Ore worth $30,000 is said to have been shipped from the mine during the early period of activity in the district. The ore consists of tetrahedrite, galena, and sphalerite sparsely scattered in a coarse quartz-siderite gangue. The deposit is within the area of siliceous limestone beds.

King of the West mine.—The King of the West mine, situated near the head of King of the West Gulch, at an elevation of 7,300 feet, was located in 1881 and was worked for the next 12 years. The property includes three patented claims and a mill site at the mouth of the gulch, where there is a 50-ton concentrating mill equipped with jigs and trommels. The vein strikes northeast and dips steeply northwest, but none of the 3,000 feet or more of workings, consisting of a 400-foot shaft and a principal tunnel, were accessible at the time of visit. The ore is said to have run 120 ounces of silver to the ton.

The principal minerals, as seen on the dump and about the mill, are galena and tetrahedrite in a quartz-siderite gangue.

Sunday Group mine.—The Sunday group lies about one-half mile west of the King of the West on the north side of the canyon. It comprises two unpatented claims which contain veins reported to have produced $15,000 or $20,000 from argentiferous galena ores. Material on one of the four dumps suggests that the ore consisted of galena, pyrite, and chalcopyrite in a gangue composed of quartz and a little siderite mixed with calcareous shale and slate fragments from the inclosing rock.

Stormy Galore mine.—The Stormy Galore group, comprising three unpatented claims, is situated near the head of West Richmond Gulch at an elevation of 7,500 feet. The mine is said to have produced $100,000 from gray copper ore containing about 400 ounces of silver to the ton, the highest-grade silver ore found in the district. Very little galena accompanies the tetrahedrite. The gangue is a mixture of the magnesian limestone wall rock and coarsely crystallized quartz. Cavities lined with quartz crystals are abundant in many specimens. The principal tunnel extends southward from a point near the creek level, but the one recently worked is 150 feet higher. Above this tunnel are two others, the four aggregating perhaps 2,000 feet of work. The vein, as exposed in next to the lowest tunnel, strikes N. 7° E. and dips 60° E., but both strike and dip vary from place to place. The stopes show it to have been from 2 to 8 feet wide, averaging perhaps 3 feet. The hanging wall is of fine-grained, bluish-gray magnesian limestone and is well defined; the footwall is of similar material but grades back through a zone of crushed and sheeted limestone into the undisturbed country rock. A narrow stringer of ore lies parallel to the vein 20 feet in the hanging wall, and another which strikes north-south and dips steeply west crosses the main vein. The mine has been worked intermittently since its discovery in 1882.

Tyrannus mine.—The Tyrannus group, consisting of five patented claims, is on the north side of West Richmond Gulch near its head, 7,700 feet above sea level and about 2,000 feet southwest of the Stormy Galore mine. A concentrating mill equipped with crusher, trommels, and five jigs is situated on the property. There are four tunnels, representing perhaps 4,000 feet of work in all, but only the lowest was accessible at the time of the writer's visit. In this the old stopes indicate a vein from 18 inches to 8 feet wide, averaging perhaps 3 feet, which strikes N. 60° E. and dips 37° NW. The inclosing rock is calcareous slate with intercalated quartzitic slate and is traversed by dikes of diorite porphyry. The mine is credited by local residents with a production of $100,000 from argentiferous galena and tetrahedrite ores averaging about 100 ounces of silver to the ton. The gangue minerals are quartz and siderite. The mine was worked intermittently from its discovery in the fall of 1882 until 1906, at first by the original locators and later by a French company.

Other mines and prospects.—Several other mineral claims are recognized in the district, but none of them were being worked in 1912, and so far as known to the writer none have produced more than a small amount of ore. Most of them are in the vicinity of Worwick hot springs. A large number of claims north of the springs are known as the Rosetta group, and others a few miles to the south as the Five Points group. None of these claims were visited during the reconnaissance.

LITTLE SMOKY DISTRICT.

The Little Smoky district, so named because it includes the area about the headwaters of Little Smoky Creek, lies east of the Rosetta district. Most of the recognized deposits are less than 10 miles southwest of Carrietown. The district embraces a large area of the Tertiary eruptive rocks and a small portion of the area of Paleozoic beds which contain the principal deposits of the Rosetta district. Both lead-silver and gold-silver ores have been exploited in the district, but the total production has been small.

The Hidden Treasure is said to be one of the more promising groups. It comprises four unpatented claims developed by a 40-foot shaft and three short tunnels; in all less than 1,000 feet of work. Considerable ore is said to be blocked out in the mine and to average 15 to 20 per cent lead, 10 ounces silver, and 0.2 ounce gold to the ton. It has produced about $8,000. Other groups in the district are the Smoky Bullion, Idaho Chief, Prince of India, Gopher, Flynn Consolidated, Stewart, and Stratford. Below these claims, along the valley of Little Smoky Creek, are the Rawley, Hollister, and Rollins placers, each of which has been worked intermittently in a small way for a number of years. The deposits of the district were not examined during the reconnaissance.

WARM SPRINGS DISTRICT.

BOYLE MOUNTAIN.

The deposits near Boyle Mountain lie within the Warm Springs district, which extends into the area from the Hailey quadrangle. Rooks Creek, a small tributary to Warm Springs Creek from the north, drains the eastern slope of Boyle Mountain and flows through an area which has produced nearly $1,000,000 from lead-silver ores and perhaps $50,000 from zinc ores. A batholithic mass of dark-gray medium-grained soda granite, locally with a phenocrystic development of the feldspars, protrudes through the Paleozoic slates and calcareous sandstones over an area of perhaps 5 square miles. The principal deposits occur near the northwest border of the granite, in part in the igneous and in part in the sedimentary rocks.

The Old Ontario and Lucky Boy mines, both acquired several years ago by the Boston & Idaho Mining Co., are the principal deposits in the vicinity of Boyle Mountain. The Ontario lies west of the creek and Lucky Boy east of it. In the canyon separating them the Boston & Idaho Co. erected a 100-ton concentrating mill in 1907 but has treated very little ore in it. The period of active production extended from 1881 to 1887, the output during later years being erratic and small.

The Ontario mine is opened by tunnels aggregating several thousand feet of work both in the granite and in the Paleozoic sedimentary rock. Two systems of veins, each offset by numerous normal faults, have been explored. At the time of visit, however, all the tunnels were inaccessible except one, and that one, which is in granite, was caved at a point 500 feet from the portal. Ore on the dump shows the vein to contain fine-grained galena, arsenopyrite, pyrite, and a little sphalerite and chalcopyrite in a quartz gangue. Specimens taken from the dump show that replacement of the granite was involved in the formation of the ore. Pyrite seems to have wandered farthest into the walls, but small patches of all the other minerals are abundant in specimens of the sericitized granite. The ores on this (west) side of the canyon were mined for silver and lead.

The Lucky Boy mine, on the east side of the canyon, was not visited during the hasty reconnaissance. It is operated for zinc ores. Specimens of the ore consist of sphalerite, pyrite, and a little galena and arsenopyrite in a quartz-siderite gangue. The mine is said to have produced 2,600 tons of 45 per cent zinc ores from veins intermittently worked for several years.

BOULDER BASIN.

General features.—The mining claims of Boulder Basin, which lies north of Wood River near the eastern edge of the quadrangle, are recorded in the Warm Springs district, which lies mostly within the Hailey quadrangle. A good wagon road leads from Ketchum up the valley of Wood River and thence up the canyon of Boulder Creek, a total distance of 16 miles. Only the last mile of the road has a steep grade and even over this freighting is done with wagons. The narrow canyon of Boulder Creek opens out near its head into a beautiful amphitheater, which is floored with meadowland dotted with several small lakes and is surrounded on the north, west, and south by precipitous cliffs from 1,000 to 1,600 feet high. Boulder Peak, on the southwest side of the basin, rises 11,100 feet above sea level, being one of the higher peaks along the divide between the drainage basins of Salmon and Big Lost rivers on the north and Wood River on the south. The floor of the basin stands at an elevation of 9,500 feet.

Except for the heavy snows in winter the conditions are excellent for mining. Timber is plentiful, water for domestic use and for power is within easy reach, and the precipitous slopes make development by tunnels particularly advantageous.

Geology.—The rock formations include a thick series of bluish and gray fine-grained quartzites and siliceous slates, which in general strike a little east of north and dip west at high angles. These are traversed by dikes that range in width from a few inches to a few hundred feet. In general the dikes follow the strike of the formations and dip 70°–85° W., many of them following bedding planes and others dipping more steeply than the bedding. They are exceedingly numerous, comprising perhaps one-third of the rock exposed in the sides of Boulder Basin. The study of them was too hurried to afford an adequate idea of their varieties and relations, but collected specimens include granite porphyry, quartz monzonite porphyry, diorite porphyry, and a rare lamprophyre identified as spessartite. The microscopic descriptions of these rocks appear in the section on the dike rocks (pp. 227–228).

Principal claims.—The principal claims in Boulder Basin and vicinity are held by two companies, the Golden Glow Mining Co. and the Boulder Consolidated Mining Co. The former owns 5 patented claims and the latter 23 unpatented claims surrounding the other group and extending southeastward. The principal output, said to be about $1,000,000, has come from the Golden Glow ground, which was located in 1879, relocated in 1882, and actively exploited during the next 10 years. In recent years small shipments have been made, those in 1911 returning $15,000 from 125 tons of ore. This ore contained from 43 to 58 per cent of lead, 1 to 2 per cent of copper, and 0.32 to 0.63 ounce of gold and 56 to 92 ounces of silver to the ton.

Golden Glow mine.—The Golden Glow mine is on the west side of the Boulder Basin cirque. Development consists of four tunnels and one shaft. The tunnels, numbered consecutively from the lowest to the highest, represent, respectively, 800, 390, 625, and 90 feet of work; the shaft is above and is 125 feet deep. The levels are about 110 feet apart and are situated nearly one above the other.

The mine contains one principal vein, which strikes in general N. 50° E. but locally turns abruptly east. The general dip is about 70° SE., but locally it is in the opposite direction, as between levels Nos. 2 and 3. The vein material is bordered by well-defined walls, to which the ore adheres firmly in most places. The space between the walls is locally filled in large part with sheeted and crushed wall rock; elsewhere with vein quartz. Three principal ore shoots have been worked. The largest shoot begins 191 feet from portal No. 2 and continues for 100 feet. Sixty-five feet below this level it is 150 feet long, but 60 feet above the level the ends draw in until they are only

5 feet apart. This continues a short distance upward and then the length again increases to 100 feet on level No. 3. Fifteen feet above this level the ore heads squarely against a smooth surface of quartzite. About 300 feet west of this shoot, beyond a dike of granite porphyry, there is another, which, as developed, ranges from 10 to 100 feet in length, averaging perhaps 30 feet. It has been opened to a depth 50 feet below level No. 3 and continues from it to the surface, 125 feet above. Ninety feet west of this shoot is the "Cache shoot," which was worked by shaft to a depth of 125 feet. It contained ore said to have averaged 55 to 60 per cent in lead and 360 ounces in silver and 3 ounces in gold to the ton. The shoot was from 10 inches to 2 feet wide and averaged about 90 feet long. In the other shoots the ore is of much lower grade, and in each the width of the vein is from 6 inches to 6 feet, averaging perhaps 20 to 24 inches.

Oxidation is almost complete down to level No. 3, where the ore is a porous quartz heavily stained with iron and manganese, containing lead carbonate in bunches and pockets. Below, the ore consists of galena and a little sphalerite, pyrite, and chalcopyrite in a quartz gangue, containing a little calcite and siderite. Proustite and stephanite are present locally in very small amounts.

Several of the dikes in these deposits cut across the veins, in places dividing a vein as would a wedge, but elsewhere causing considerable offsets, as in level No. 3, where, on the west side of the dike, the vein is shifted 50 feet to the north. Locally, however, stringers of primary ore cut the dike rocks, suggesting that the injection of the dikes and the formation of the veins were nearly synchronous. The sequence of dike injection is not known, but in tunnel No. 3 granite porphyry traverses the ore, and in tunnel No. 2 ore of the middle shoot shows replacement phenomena against a lamprophyre dike.

Boulder Consolidated mine.—The Boulder Consolidated group comprises 23 claims, which surround the Golden Glow group and extend southeastward across the high elbow in the west rim of Boulder Creek canyon and down to the creek level, nearly a mile distant. Here a long crosscut enters the canyon side at an elevation of 7,950 feet, and so rapidly attains depth that at the present face, 1,000 feet from the portal, it is said to be about 1,500 feet below the surface. At a distance of 4,000 feet, according to the company surveys, the face will be directly below the Golden Glow ore body. The tunnel extends N. 64° W. and traverses, almost at right angles to their strike, steeply dipping quartzite beds which have been intruded by dikes, principally of granite porphyry, so numerous that more than half of the total length of the tunnel is in igneous rock.

Stringers of pyrite accompanied by a little sphalerite and zinc blende occur at several places in the tunnel, but no ore body of minable size had been found at the time of visit. Small prospect tunnels and pits at several places on the surface show evidence of mineralization, and it is hoped that the crosscut will reveal ore beneath some of these. The main object in driving it, however, is to reach a point beneath the Golden Glow ore body 1,300 feet below the lowest Golden Glow level.

GALENA DISTRICT.

The Galena district has always occupied a subordinate place in the mining activity of the region. A 30-ton capacity smelter was built at the town of Galena, best known as a stage station, in the early eighties, but it ran for only a short time and with indifferent success. The principal mineral locations in the district are the Senate, Gladiator, and Carbonate Hill mines. Their production was small, and during recent years assessment work has not been kept up on most of the claims. The settlement of Galena is well within an area of Tertiary eruptive rocks, although some of the creeks that join Wood River near the station probably head in the older formations. The deposits were not visited. From Galena a trail leads north over the divide to Germania and Washington basins, and from these camps much of the ore for the local smelter is said to have been obtained.

EAST FORK DISTRICT (GERMANIA AND WASHINGTON BASINS).

GENERAL FEATURES.

The deposits of Germania and Washington basins are on the north side of Germania Creek, a tributary to East Fork of Salmon River near its head. They are in the East Fork mining district.

The district is high and mountainous, with summits above 10,000 feet in elevation, which rise abruptly from drainage lines 3,000 to 4,000 feet lower. Steep slopes that are thickly covered with fir and pine make up most of the area, but about the heads of many of the glaciated canyons cliffs rise almost vertically for several hundred feet, and upon these there is no vegetation. Washington Basin comprises the upper end of one of these glaciated canyons and lies just north of Germania Basin, which is shown on the north edge of Sawtooth topographic sheet. Both basins drain to the southeast.

The area is 50 miles by wagon road from Ketchum, the nearest railroad point. The route leads from Ketchum to the head of Wood River, over the Galena summit into the valley of Salmon River and thence up Pole Creek, over a fairly easy summit into Germania Basin and on into Washington Basin. The area also may be reached by trail from Clayton, about 25 miles to the north.

PRINCIPAL CLAIMS.

Lead-silver deposits.—Lead-silver deposits were discovered in Germania Basin in 1880 and were worked for the seven years following. Two principal groups of claims were recognized—the Tyrolease, comprising two unpatented claims, and the group owned by the Wood Livestock Association, comprising six patented claims. The Tyrolease made only a small production, but the deposits of the other group shipped ore worth more than a quarter of a million dollars. The Parnell claim, separately owned, is said to have produced $125,000. During this period of seven years two or three other lead-silver veins that crop out in the south wall near the head of Washington basin were also being worked, producing possibly $50,000.

Gold quartz ledges.—Prior to 1894 no serious attention was given to the large low-grade gold-quartz ledges, five in number, which crop out in a low ridge of igneous rock that divides Washington Basin lengthwise into north and south parts. Since 1894, however, the number of claims in the area on which annual assessment work is done has increased from 2 or 3 to 20 or more. Eleven of these comprise the Empire group, on which the only noteworthy development has been accomplished. A few years ago this group was bonded, but the option was forfeited.

The rock formations in the vicinity comprise a thick series of sedimentary beds invaded by masses of porphyritic quartz monzonite. The sedimentary rocks include fine-grained quartzite overlain by dark-colored massive dolomitic limestone, which grades into a succession of alternating blue and white limestone and next into black slate, comprising in all 1,500 feet or more of beds similar to those exposed in the south side of Washington Basin. The igneous rock consists of orthoclase, plagioclase, quartz, and biotite with interstitial areas packed with micropegmatite.

Last Resort vein.—The Last Resort vein strikes N. 60° E. and dips 40° SE. It may be traced through three claims, except for a gap of about 400 feet, and averages in width about 6 feet, although it is locally as much as 12 feet across. It is developed by a tunnel 112 feet long, which if continued for 1,500 feet would attain a vertical depth of 350 feet. It is also exposed in a dozen or more short tunnels, open cuts, and pits. In all the exposures the vein material is an iron-stained coarse-grained quartz with scattered patches of honeycomb quartz. It is said to carry $3 to $5 in gold to the ton.

Empire vein.—The Empire vein or ledge strikes N. 25° E. and dips 55° SE. It is entirely inclosed in the porphyritic granite and crops out at short intervals through four claims. Its average width is about 30 feet, though in one place on the crest of the ridge it is 72 feet across. Development consists of two tunnels, two shallow shafts, and several trenches. The lower tunnel is 450 feet long, the upper one 150 feet. The vein material is coarse-grained bluish quartz and partly replaced quartz monzonite. Near the surface it is intensely oxidized in most places, but at a depth of a few feet primary minerals appear. Arsenopyrite occurs as small patches and isolated prismatic crystals in the northern part of the vein. In the southern part pyrrhotite, with about an equal amount of intermixed quartz and diopside, forms a band 15 to 20 feet wide next to the hanging wall. Thin sections of this material show clearly that the pyrrhotite replaces quartz monzonite, the quartz of which remains. The feldspar and biotite crystals are completely transformed to pyrrhotite and diopside, the feldspar showing a slight tendency to be in the centers of diopside areas. Much of the diopside also is poikilitic with respect to quartz grains. Near the crest of the ridge the vein incloses a large lenticular mass of quartz monzonite in which considerable sphalerite occurs as isolated patches and stringers, some of which are 3 to 4 inches across. The sphalerite is accompanied by a little galena, pyrite, stibnite, pyrrhotite, and arsenopyrite. The quartz monzonite here is intensely sericitized and locally is greenish gray and of a silky luster. The feldspars are changed to a felted mass of sericite, which incloses grains of the sulphide minerals. Chlorite and a little magnetite occur in areas probably occupied originally by biotite. In one of the thin sections of the sulphide ore the main mass, pyrrhotite, is intricately fractured and traversed by iron-stained quartz of netlike distribution.

The tenor of the Empire ledge matter is not definitely known, but pannings from outcrop material show the presence of gold in many places. Mr. George Z. Blackman, of Clayton, Idaho, the owner, claims that ore from a 30-foot face in the lower tunnel averages $12 to the ton in gold, although it would seem from the panning of the specimens collected by the writer that this estimate is too high. On the crest of the hill the outcrop is said to contain $6 to $7 in gold to the ton.

West Empire vein.—One hundred feet west of the Empire is a parallel ledge 15 feet wide known as the West Empire. It has not been developed.

Vein east of the Empire.—East of the Empire, perhaps 100 feet, another quartz ledge appears at the surface for a considerable distance, but has not been explored.

Reconstruction vein.—The Reconstruction vein lies 400 feet east of the Empire and parallel to it. It is about 20 feet wide and, as exposed at the time of the examination, is an iron and manganese stained honeycombed quartz throughout. Sulphide minerals were not seen in any of the ore, but as the vein corresponds to the Empire in general appearance, it is probable that about the same mineral association characterizes the primary ore. Samples taken across the entire width of the vein are said to show by amalgamation tests a possible recovery of nearly $10 to the ton in gold. The gold pans readily but is very fine and flaky.

VIENNA DISTRICT.

GENERAL FEATURES.

The Vienna district embraces an unorganized area in the western part of the quadrangle about the headwaters of Smiley Creek, a tributary of Salmon River, and of Vienna Creek, a tributary of South Fork of Boise River. During the six years following the discovery of mineral in the district in 1879 the camp was an active mining center. The town of Vienna was a flourishing settlement of perhaps 1,000 inhabitants, 200 or more buildings, and a 50-ton capacity stamp and chlorination mill. None of the buildings now stand, however, though great piles of timber mark their positions and clearly bespeak the rapid depreciation of abandoned improvements in this area of heavy snow and long winters. The settlement is completely razed, and is about as desolate a place as one could imagine. Great tiers of cordwood, comprising possibly 20,000 cords in all, piled in the gulch and about the mill, tend to confirm the statement of former residents that activities in the district ceased abruptly. About eight years ago the claims were sold for taxes, and during 1912 three of them were worked under bond and lease from the person who bid them in. Many companies operated in the district during the first two or three years, but the claims were gradually consolidated into two principal groups, the Solace, with 16 patented claims, and the Vienna, with 33 patented claims.

PRODUCTION.

The production of the district can not be stated exactly, but is probably about $1,000,000. Statements from the reports of the Director of the Mint for 1881 to 1884 afford some scattered and fragmentary information which can not be satisfactorily tabulated. The Vienna mill seems to have been erected soon after the discovery of the Mountain King ledge, in June, 1881, and to have produced $300,000 during 1883 and about $200,000 during 1884, all in silver bullion containing some gold. In 1883 the Mountain King, a claim of the Vienna group, is said to have produced $103,600 from ore containing 20 to 30 ounces of silver to the ton. During this period other claims in the district were producing some ore, but the amount is not a matter of official record. The production after 1884 is not given specifically for this district.

PRINCIPAL MINES.

Development.—The mines are about 2 miles south of the old town of Vienna, near the head of the west branch of Smiley Creek. Development is extensive, possibly aggregating 15,000 or 20,000 feet of work, as estimated from the size of numerous dumps on both sides and around the head of the canyon. The principal workings of the Solace mine are about half a mile south of the Vienna.

Geology.—The deposits of the district occur well within the area of the Idaho granite, which crops out over most of the central part of the State. Here the granite is a light-gray equigranular rock, which along the veins is intensely sericitized, quartz being the only mineral in it which is unaltered. Along the gulch a few miles below the mine a little limestone float was seen, but it is not known to have any relation to the ore deposits and is certainly of small extent within the drainage area of Smiley Creek. About a mile below the old town of Vienna is the southwestern side of a wide belt of Tertiary lavas which extends northward for many miles along the course of Salmon River.

Mountain King mine.—At the time of the writer's visit only the Mountain King workings were accessible. They had recently been cleaned out in part by a group of men who held three claims of the Vienna group under bond and lease, and who were seeking lead-silver ores in the old silver-quartz stopes. This is said to be the only mine in the district which contains important amounts of lead ores, and as lead was not desired in the chlorination mill owned by the old company it was not removed from the mine. The ore occurs along a crushed zone that strikes N. 60° W. and dips 51° NE. in the upper levels and 80° in the lowest or No. 4 level. Development comprises about 6,000 feet of work in four drifts on the vein. As shown by the old stopes the ore body was about 700 feet long and ranged in width from a few inches to 15 feet, probably averaging about 4 feet. It is said that material from these stopes averaged between 20 and 30 ounces of silver to the ton and contained a noteworthy amount of gold. The best lead ore was found on level No. 3 near raise No. 9, where a small vein which strikes N. 40° E. intersects the main lode. The silver-quartz ore occurred as a band 8 to 20 inches wide alongside the galena ore, either next to the hanging wall or next to the footwall. Both sorts of ore show abundant evidences of replacement of crushed granite. Next to the vein, pyrite as isolated cubes and stringers is developed in the granite, and sphalerite and galena replace blocks of wall rock within the fissure. The granite is intensely sericitized adjacent to the fissure, and locally chlorite is abundantly developed. The lead ore is irregularly distributed along the fissure and ranges in width from 1 inch to 6 feet.

Assay records supplied by T. H. Williams, who with two associates held the bond and lease in 1912, are as follows:

Assays of ore from veins of Mountain King mine, Idaho.

Width in inches of vein sampled.	Gold.	Silver.	Lead.	Zinc.	Insoluble.	Sulphur.	Iron.	Copper.
	Ounces.	*Ounces.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
16......	1.07	26.4	28.0	14.9	4.6	26.1	13.5	0.3
24......	1.58	11.1	6.8	4.0	27.2	21.6	21.8	.2
20......	.98	4.9	1.2	12.4	10.4	34.0	25.6	.2
72......	.58	6.8	11.4	14.2	27.8	22.4	14.3	.2

Three carloads of hand-sorted ore said to average $50 to the ton were shipped from the mine in 1912. This ore consisted of galena, sphalerite, and pyrite in a coarse-textured quartz gangue.

SAWTOOTH DISTRICT.

The Sawtooth district, which embraces a large area south and southwest of Alturas Lake, was not visited during the reconnaissance. The district was the seat of an important mining industry from about 1880 to 1888. During much of this time about 150 men were employed in the area and ore said to have been worth nearly $1,000,000 was produced. Detailed records of this early activity are not available, but in the reports of the Director of the Mint for 1881 to 1884, inclusive, brief references to the camp appear in the notes on Alturas County, which then included the area. Deposits were opened on Beaver, Eureka, and Jake gulches, all of which produced high-grade silver ore, some of it containing as much as 4,000 ounces of silver to the ton, but after two or three years the Silver King and Pilgrim mines, both owned by the Columbia & Beaver Co., were the principal producers. A 20-stamp mill erected near the town of Sawtooth made its first run in the fall of 1883, producing $60,000 worth of bullion in 45 days.

The mode of occurrence of the ore is said to be similar to that at Vienna. All the deposits are veins in granite. The principal ore minerals are proustite, cerargyrite, and silver-bearing sphalerite in a quartz gangue. Galena is notably scarce and in most places is absent. The district is extensively developed, but work was abandoned so long ago that all the tunnels are reported to be caved. The Silver King shaft, 600 feet deep and the most extensive working in the district, is in the flat of Beaver Creek. The workings are entirely flooded. This mine is said by those who worked in its lower levels to contain a 16-inch band of ore which carries 350 to 400 ounces of silver to the ton and a little gold. The silver occurs as proustite and a "fine-grained greasy substance," which the miners called "black metal." The mine was worked from 1881 to 1888 and according to the statement of former residents of the district is reputed to have produced $700,000, principally during the last two years in which it was operated.

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SALINES IN THE OWENS, SEARLES, AND PANAMINT BASINS, SOUTHEASTERN CALIFORNIA.

By Hoyt S. Gale.

INTRODUCTION.

The salt-incrusted valley floor commonly known as Searles Lake, in southeastern California, has lately come into prominence through the widespread interest in the search for an available source of potash in this country and the apparently promising prospects this locality affords of a considerable commercial production in the near future. The estimate that this deposit contains 4,000,000 tons of water-soluble potash salts, an estimate made with the first public announcement concerning it, in March, 1912, seems to have been amply confirmed by subsequent developments. That this amount of potash salts will actually be produced and placed on the market can not yet be considered assured, as, of course, the quantity that may be recovered depends on many factors, but so far as can be judged from the evidence available it seems that this deposit is the most promising immediate source of commercial potash in the United States.

The present account is a preliminary statement or review. It is not based on exhaustive field studies, but is rather the result of necessarily brief and hasty trips made through this and other parts of the Great Basin in pursuit of the general plan of investigations adopted in this work. These trips have resulted in a considerable collection of scattered data. The main features of the lake history and the deposition of the salines through the drying up of the lake waters are believed to be pretty clearly understood, and it is the present purpose to give a general account of these features.

This paper will therefore summarize the history of the waters in which these salts are believed to have been concentrated and through whose ultimate disappearance various saline and other deposits were laid down. Waters that formerly filled Owens Valley until they overflowed, flooding successively lower and lower basins, formed for a time a chain of large lakes in what is now the desert region of southeastern California. These flood waters passed from Owens Valley, the principal source of the water supply, through Indian Wells, Searles, and Panamint valleys, in each of which there was an extensive lake. Finally the waters are believed to have overflowed also into Death Valley, and there the physiographic record has not yet been completely deciphered.

An attempt to understand the lake history of any one of these basins involves a consideration of all the rest, as each played its own independent part in the history of the whole system, and it appears that in no two of the basins is the present result even approximately the same. The extensive saline deposits at the bottom of the Searles Basin are a result of the overflow of waters from the shallow Owens Basin, but they were also influenced by the spreading out of these waters in Indian Wells Valley to form a broad, shallow lake in which the bulk of suspended sediment was probably laid down and beyond which the clarified and concentrating waters drained into the deeper and more isolated Searles Basin. The fact that the Searles Basin for a time overflowed into Panamint Valley and that the Panamint probably overflowed similarly into Death Valley evidently did not prevent the accumulation and deposition in the Searles Basin of an immense mass of solid crystalline salts and mother-liquor brine. It is the purpose to point out in the present paper the more salient distinguishing features and relations of these several basins and to suggest interpretations that may be placed on their influence in saline deposition. The general position and relations of these lakes and their drainage basins are shown on the index map forming Plate V, which also shows their relation to other known Quaternary lakes in this part of the Great Basin and the number and distribution of the present intermittent lakes or playas in which no record of Quaternary lakes has been discovered.

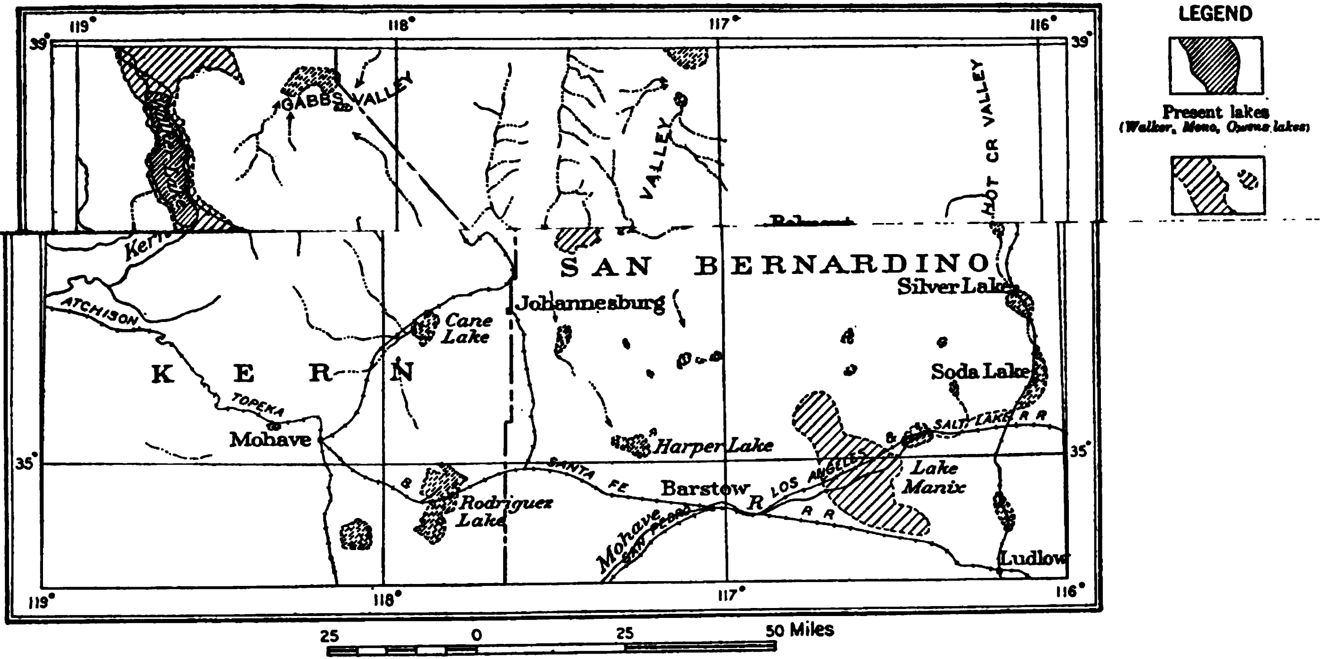
The following discussion is therefore divided into three main parts—first, Owens Lake and the Owens Basin; second, the Searles Basin and the saline deposits contained therein; and third, the ancient lake of the Panamint Valley, with a note as to its probable former connection with Death Valley:

THE OWENS BASIN.

GENERAL FEATURES.

Owens Valley is a long, open, troughlike depression lying immediately west and at the very foot of the highest part of the Sierra Nevada, in Inyo County, southeastern California. It is an extensive basin, about 140 miles in length and 20 to 40 miles in width.

Owens River is one of the few larger perennial streams of the Great Basin region. Its water is derived mainly from the west side of its valley, in tributaries that rise among the snow-covered summits and more or less timbered flanks of the very highest part of the Sierra Nevada. This river constitutes the principal and in fact almost the only source of water supply to Owens Lake, other tributaries, such as



INDEX MAP SHOWING THE GENERAL POSITION OF THE OWENS-SEARLES-PANAMINT LAKE SYSTEM, CALIFORNIA.

Cottonwood Creek and springs rising about the shores of the lake, being relatively insignificant.

Owens Valley is believed to have originated as an inclosed and undrained basin through profound faulting, whereby large blocks of the earth's crust have been irregularly tilted against one another. In its origin the valley is thus doubtless similar to most of the inclosed drainage areas of the Great Basin region. These displacements are still occurring, as is shown in Owens Valley itself by scarps recently formed by faulting on both sides of the valley, movement along these fractures having accompanied recent earthquakes. One of the most violent of which there is historical record was an earthquake that happened in 1872. The major mountain-building movements to which the present configuration of the basins and intervening mountain ranges may be ascribed took place during late Tertiary and early Quaternary time. The subsequent geologic history of these basins may be summarized briefly as one of extensive alluviation, by which the valleys have been widely filled with outwash derived from the uplifted mountain areas. Before the final lake period began a topography essentially like that of the present day was developed. In the alluvium-filled basins thus formed the glacial lakes expanded, and the shore lines and other traces of their waters have been but slightly modified by erosion or by other changes since their waters have disappeared.

OWENS LAKE.

GENERAL FEATURES.

Owens Lake, the only existing remnant of the former lake system referred to above, is a large, shallow body of water in the extreme southern part of Owens Valley. Its water is a dense brine, containing common salt, soda, borax, and other salts in solution. The lake lies in a depression which has no outlet, so that its volume depends on its water supply, or on the relation of inflow to evaporation.

Owing chiefly to variation in precipitation from year to year, the lake surface is almost constantly changing in height, and the area of its water surface fluctuates considerably with the rise and fall of the water over the broad, flat shores. The outline of the lake as determined by surveys of the bureau of waterworks and supply of Los Angeles is shown on the accompanying map (Pl. VI), which gives also, by contours, the first accurate record on file of the character and depth of the lake bottom.

As determined by these surveys, the area of the water surface in February, 1913, was 62,267 acres, or 97.2 square miles, and the maximum depth of the water was 29.6 feet. The elevation of the water surface at this date was 3,577 feet.

CHANGES OF WATER LEVEL.

The recorded changes of water level are shown in the following table, compiled in greater part from records previously published,[1] supplemented by data from the Los Angeles waterworks surveys and other sources.

Elevation of water surface, Owens Lake, Cal.

	Elevation of water surface.	Elevation above minimum recorded level.
	Feet.	*Feet.*
1872, "before irrigation was started in the Owens Valley"	3,597.00	30.00
1876	[a] 3,586.40	19.40
1905, March 30	3,568.70	1.70
October	3,567.00	
1908, March 4	3,575.95	8.95
March 29	3,575.73	8.73
April 19	3,575.78	8.78
April 26	3,575.90	8.90
May 28	3,575.60	8.60
June 4	3,575.40	8.40
1909, May 1 (water reported higher than it had been for many years).		
1910, July 22	3,575.98	8.98
September 21	3,374.98	7.98
October 28	3,574.71	7.71
December 1	3,574.89	7.89
1911, January 5	3,575.29	8.29
February 8	3,576.11	9.11
July 12	3,577.35	10.35
July 28	3,578.03	11.03
November 1	3,577.35	10.35
November 5	3,577.50	10.50
December 3	3,577.60	10.60
1913,[b] February	3,577.00	10.00
July 3	3,572.90	5.90
August 7	3,572.30	5.30
September 4	3,572.00	5.00
October 13	3,571.47	4.47
November 9	3,571.42	4.42
December 4	3,571.40	4.40
December 28	3,571.46	4.46

[a] Calculated from depth given by Loew.

[b] For these determinations the writer is indebted to Mr. William Mulholland, chief engineer bureau of waterworks and supply, Los Angeles, and to Mr. Charles H. Lee, hydraulic engineer, Los Angeles, who was in field charge of the observations and surveys, including the map (Pl. VI) and diagram (fig. 58).

Thus it appears that the fluctuations of the lake level within recent historic time have been considerable. It may be that this fluctuation should be ascribed in large part to the influence of irrigation, which, by increasing the surface for evaporation, has undoubtedly reduced the amount of water that would otherwise have annually reached the lake. However, the lake seems to have reached the recorded minimum in 1905, and since that time the amount of water diverted for irrigation has probably not decreased, yet the lake level has been considerably higher. It is of interest to note that the recorded maximum occurred in 1872 and, for comparison in this connection, that the highest water level recorded by measurements at Great Salt Lake was in 1873. The variations of lake level and of

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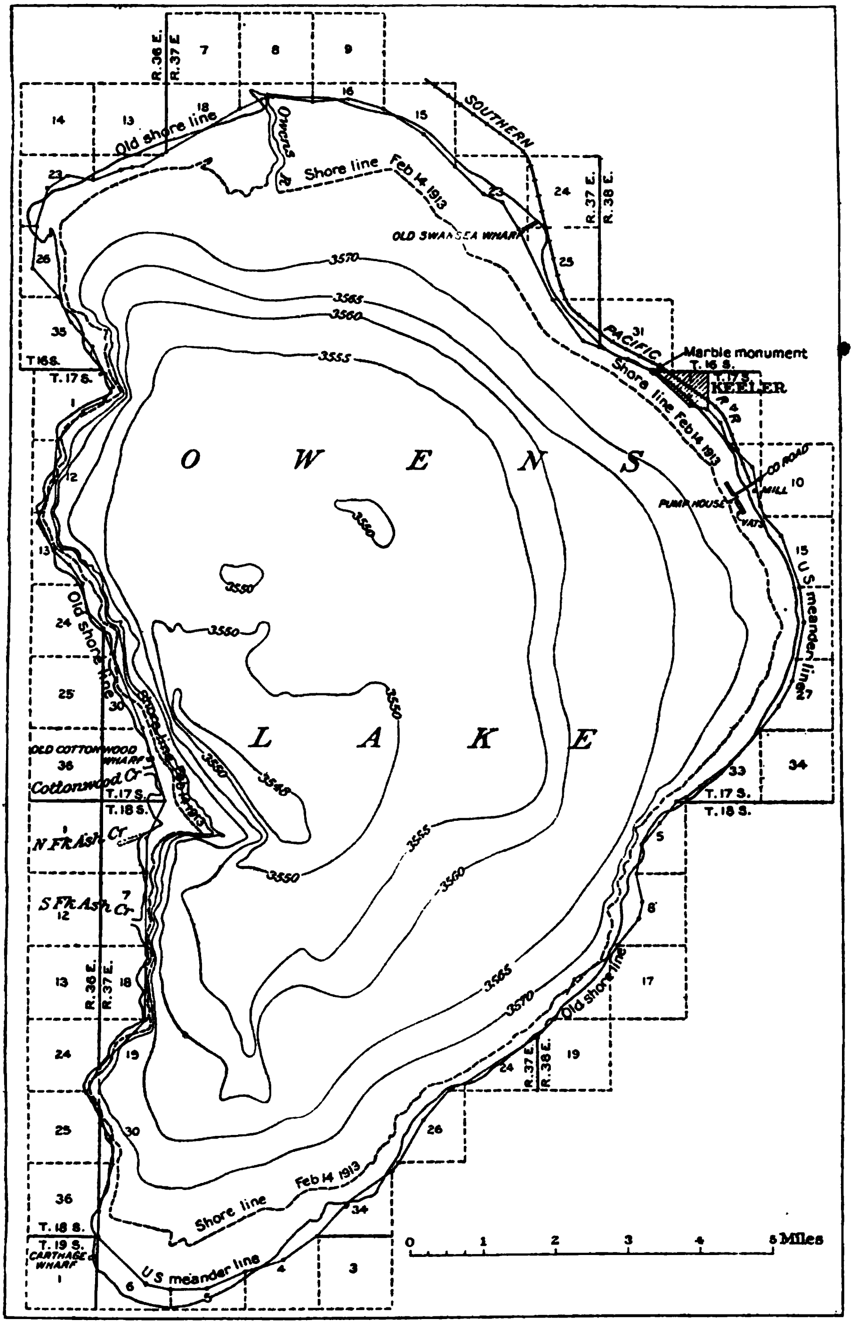
[1] McGlashan, H. D., and Dean, H. J., Water resources of California, Part III: Stream measurements in the Great Basin and Pacific coast river basins: U. S. Geol. Survey Water-Supply Paper 300, p. 225, 1913.



MAP OF OWENS LAKE, CAL., SHOWING CONTOURS OF LAKE BOTTOM.

From surveys of Los Angeles Aqueduct Commission.

lake volume are of special interest in connection with the record of concentration of the lake waters, as shown in the table of analyses on page 258.

AREA AND VOLUME OF LAKE.

The area and volume of the lake at its various water levels have been computed by Charles H. Lee for the Los Angeles Aqueduct Commission, and a summary of the results is given in the accompanying diagram (fig. 58) from data obtained by planimeter from contours based on numerous soundings.

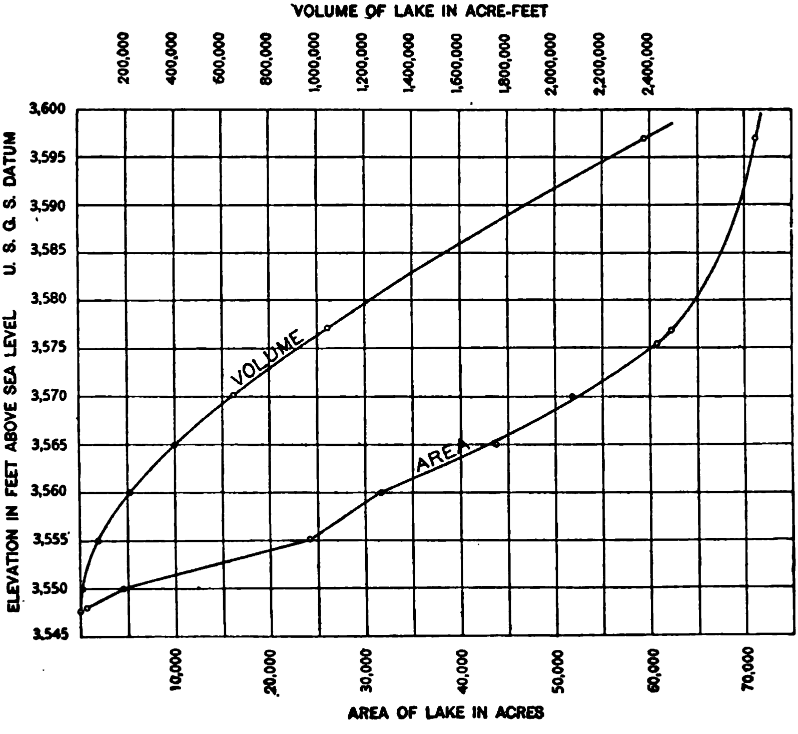


FIGURE 58.—Area and volume curves for Owens Lake basin, Cal. (From Charles H. Lee, in report for Los Angeles Aqueduct Commission.)

ANCIENT WATER LEVELS AND FORMER OVERFLOW.

As has already been explained, Owens Valley was the site of a former larger and deeper lake that rose to a level at which it overflowed, the outlet being by way of the valley through Haiwee Meadows and beyond, through the pass on the south side of the basin. The evidence of this history is very clear, consisting in old high beach lines, wave-cut terraces and sand bars built along the old shores, now high above the lake water level, and the distinctly marked channel of a long-continued overflow by which the surplus waters passed on to the lower basins south and southeast of Owens Valley. The area of the former lake in Owens Valley at the level of its last overflow (3,760 feet) is computed to have been about 240 square miles.

The flooding of these basins is supposed to have been coincident with the general extension of glaciation in the higher adjoining mountain ranges and is consequently referred to the glacial epoch of the Quaternary period. It is generally agreed that there were at least two periods of ice advance in this part of the country during the glacial epoch, and for Lakes Lahontan and Bonneville it is thought that there may have been two corresponding stages of maximum flooding in the basins and an intervening period of very complete desiccation. No additional data in this matter seem now to be available in the Owens, Searles, and Panamint basins, although nothing that would tend to contradict such a hypothesis has yet been noted. (See p. 319.)

The uppermost water line of the former lake in the Owens Basin is stated by Lee[1] to have remained for a long period at or about the 3,790-foot elevation, as shown by beach lines on the east slope of the Alabama Hills, and this line is 220 feet above the present water level. Barometric observations on the distinct gravel-covered beach remnants just northeast of Swansea, checked at the bench mark near the railroad at Swansea station (3608), show an uppermost distinct beach and barrier bar at an elevation of about 3,700 feet and another very distinct beach terrace about 30 feet lower. Corresponding old shore lines also show along the valley margin between Swansea and Keeler. The divide at the south end of the valley now lies in or between the Haiwee reservoirs of the Los Angeles aqueduct and is shown by the aqueduct surveys to be about the elevation of water level in the reservoir, which when filled is to be 3,764 feet.[2] The present divide, however, appears to be over a comparatively modern alluvial dam that has partly filled the old overflow channel. The former channel itself, however, seems to have been eroded in Tertiary white tuffs or shale, the erosion of the channel doubtless representing a period during which the lake level gradually lowered from the 3,790-foot level to 3,760 feet, the water finally standing 190 feet above the present lake level, before it began to subside by evaporation alone within its inclosed basin. It is possible—in fact, it seems quite probable—that recent fault disturbances to which the valley has been subjected may have locally offset these former shore markings, and the elevations obtained from them may therefore be subject to some latitude of interpretation.

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[1] Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Cal.: U. S. Geol. Survey Water-Supply Paper 294, p. 73, 1912.

[2] Bur. Los Angeles Aqueduct Seventh Ann. Rept., November, 1908.

COMPOSITION OF WATER.

The composition of the water of Owens Lake is recorded in a series of analyses that have been made from time to time, beginning with one by J. Arthur Phillips from a sample collected in January, 1866. Most of these have been published before,[1] but one analysis and several other late determinations are added in the following list. These analyses agree fairly well. As would be expected, the principal variation is in the concentration of the water, which is naturally the result of or is concomitant with the fluctuating volume of the lake already referred to.

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[1] Phillips, J. A., The alkaline and boracic lakes of California: Pop. Sci. Review, vol. 16 (2d ser., vol. 1), pp. 153-164, London, 1877.

Loew, Oscar, The Owens Lake, Inyo County, Cal.: U. S. Geol. Surveys W. 100th Mer. Ann. Rept. for 1876, p. 190.

Chatard, T. M., Natural soda, its occurrence and utilization: U. S. Geol. Survey Bull. 60, pp. 27-101, 1890

Bailey, G. E., Saline deposits of California: California State Min. Bur. Bull. 24, p. 95, 1902.

Lee, W. T., Geology and water resources of Owens Valley, Cal.: U. S. Geol. Survey Water-Supply Paper 181, pp. 21-22, 1906.

Van Winkle, Walton, and Eaton, F. M., The quality of the surface waters of California: U. S. Geol. Survey Water-Supply Paper 237, p. 122, 1910.

Clarke, F. W., The data of geochemistry, 2d ed.: U. S. Geol. Survey Bull. 491, p. 58, 1911.

Waring, G. A., Springs of California: U. S. Geol. Survey Water-Supply Paper 338 (in press).

Composition of salts dissolved in water of Owens Lake, Cal.

[Calculated to percentage of anhydrous residue.]

	1	2	3	4	5	6	7	8	9[a]	10
Date of collection	Jan., 1866	Oct., 1876	Mar., 1882	Sept., 1886	Quoted in 1902	July, 1904	Aug., 1905	May, 1912	Oct., 1912	Feb., 1914
Analyst	Phillips.	Loew.	Lunge.	Chatard.	Unknown.	Wrinkle.	Stone & Eaton.	Bailey.	Hicks.	Hicks.
Specific gravity	1.076	1.051	1.063	1.062 at 25° C.		1.186	1.195	1.0845	1.0977 at $\frac{21°}{20°}$ C.[a]	1.0972 at $\frac{23°}{20°}$ C.
Cl	25.12	22.20	25.80	25.67	25.75		24.82		25.56	
SO_4	10.06	15.47	9.97	9.95	10.00		9.93		9.96	
CO_3	23.22	21.73	23.60	23.51	18.34		24.55		22.18	
PO_4	.23						.11			
B_4O_7				.48	.50		.14		1.92	1.92
NO_3							.45			
Na	38.55	35.78	40.63	37.83	42.79		38.09		38.07	
K	2.05	4.55		2.18	2.20		1.62		2.10	2.07
Li							.03			
Ca				.02			.02			
Mg				.01			.01			
SiO_2	.77	.28		.29	.29		.14		.21	
Al_2O_3				.04	.13		.04			
Fe_2O_3				.02						
As_2O_3							.05			
Total anhydrous salts, percentage of original sample	8.74	6.05	6.88	7.27			21.37	9.59	10.95	10.95

[a] The specific gravity given is that of the solution at the temperature of 21° C. referred to water at 20° C.

1. Analysis by J. Arthur Phillips quoted in his article already cited. As there stated in grains per imperial gallon, it includes 16.94 grains of organic matter, which has been eliminated in the recalculation to anhydrous residue here given. The original statement of this analysis in the reference here given differs from the reference which has been generally quoted from Bulletin 24 of the California State Mining Bureau, page 95, although apparently referring to the same analysis.

2. By Oscar Loew, loc. cit.

3. By George Lunge, one of two analyses quoted. Sulphuric acid and alkali, vol. 2, pt. 1, 1890.

4. By T. M. Chatard, loc. cit.

5. Quoted by Gilbert Bailey, loc. cit.; no date or name of analyst given.

6. Determinations by Noah Wrinkle, quoted by W. T. Lee, loc. cit. The lake is reported to have been 16 feet lower at this time than it was in 1894.

7. Recalculation of analysis as quoted by F. W. Clarke, loc. cit.

8. Sample collected by F. L. Young, superintendent of Inyo Development Co., Keeler, Cal., from sump at end of the company's pipe line, where water is said to have been 9 feet deep. Partial analysis by R. K. Bailey in Geological Survey laboratory at Washington.

9. Sample collected by Hoyt S. Gale at same place as sample 8, below water surface. Analyzed by W. B. Hicks in Geological Survey laboratory at Washington.

10. Sample collected by F. L. Young at same place as sample 8. Partial analysis by W. B. Hicks in Geological Survey laboratory at Washington.

In all these analyses bicarbonate in the original solution is reduced to carbonate in the anhydrous residue and is so expressed. For the sample of October 23, 1912, analyzed by W. B. Hicks, the bicarbonate radicle (HCO_3) amounted to 4,790 parts per million by weight.

One notable feature brought out by comparison of these results is the divergence in boric acid determinations. Mr. Hicks states that his determinations of boric acid have been carefully checked by various methods and are believed to be correct. Where boric acid has not been determined in the other analyses, it was probably included in the expression of results as carbonate. It is also to be noted that the sample collected August 21, 1905, was of the maximum recorded density, almost exactly double that of the present day, and that the lake was reported to have been practically constant at that level and density for three years previous to that time.

On the assumption that the lake level in October, 1912, was about 3,577 feet at the time when the last recorded sample for fairly complete analysis was taken, a volume of approximately 1,000,000 acre-feet of water is indicated. A calculation from the analysis quoted shows that the lake waters contain in round numbers as follows:

Approximate total content of chlorine, sodium, etc., in the water of Owens Lake.

	Short tons.
Chlorine	40,000,000
Sodium	60,000,000
Potassium	3,360,000
Anhydrous boric acid (B_2O_3)	3,070,000
Total anhydrous salts	160,000,000

These figures are considerably in excess of the estimates made by Loew,[1] who calculated 5,000,000 tons of sulphate of potassa; but Loew's figures for volume were very moderate even for the data which he then had, and the present estimates have the advantage of much more exact volume computations.

The estimate that over 3,000,000 tons of potassium is dissolved in the Owens Lake water is doubtless not far from correct, but this figure is not intended for direct comparison with the estimates of available potash given for the Searles Lake deposits. The percentage of potash in the Owens Lake water is so much lower than that in the Searles brine that there is much doubt if the Owens Lake water may ever be used for the extraction of this substance, unless it is obtained as a by-product of some other process, or unless the water shall reach a greater natural concentration. There is, of course, a vastly greater amount of potassium in the water-soluble salts in the Searles basin than that included in the 4,000,000-ton estimate.

The anhydrous salts of Owens Lake, if entirely freed of water and deposited in the present lake bottom, would cover an area of about 25 square miles, as computed from the table on page 255, and have a thickness in the deepest part of the basin of 5 or 6 feet. Of course no such complete evaporation of the water would occur naturally, and both water of crystallization and the dense mother liquor naturally retained with such a deposit would increase the bulk very considerably over the figures given above. Perhaps the water so retained would constitute more than two-thirds of such a deposit, and if so its area would be at least 40 square miles and its greatest depth over 10 feet.

OWENS RIVER.

SOURCE OF THE SALTS.

The salts now contained in solution in Owens Lake were undoubtedly derived by the slow accumulation and concentration of the river waters entering the basin. As this water supply is and has been continuous, and as there has not been any overflow or outlet except by evaporation for a very long time, it is clear that salts naturally dissolved in the river waters, though in very dilute solution, have eventually concentrated into the dense brine which is now found in the lake. Some figures are given further on which will not only represent the rate at which the waters and their contained salts are accumulating but which may also afford a basis for estimating the length of the present period of salts accumulation.

VOLUME.

The volume of Owens River has been very carefully measured—in fact, the records are more than ordinarily complete owing to the careful investigations that have been conducted preliminary to the diversion of its waters for the Los Angeles municipal water supply. Discharge measurements at several stations along the river have been taken for a period of many years. Those available for the lowest station, opposite Lone Pine, some 12 miles above the mouth, are as follows:

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[1] U. S. Geol. Surveys W. 100th Mer. Ann. Rept. for 1876, p. 190.

Total discharge of Owens River near Lone Pine, Cal., about 12 miles above the mouth, 1909–1912.

	Acre-feet.
1909	358,100
1910	249,900
1911	416,000
1912	194,900
Average (4 years)	304,725

From these figures the present annual discharge may be assumed to average about 300,000 acre-feet, although it is to be noted that the variation is large. The flow for 1911 was more than double that for 1912; and it is stated that the total flow during 1906 or 1907, which were the wettest years since 1903, was nearly double that of the driest year of the same period.

COMPOSITION OF DISSOLVED SALTS.

The dissolved mineral salts in Owens River water have also been very carefully studied. The content of saline matter in the river water varies with the volume of the river. It is generally true that the periods of greater flow show more dilute water, and the opposite is believed to be true also, a general relation which is borne out by the two very complete yearly records given herewith, as well as in a more general way by the details of the monthly records. A report has been published giving an estimate of the salt content and the total weight of dissolved salts in Owens River water at Charlies Butte from November, 1906, to November, 1907, inclusive, a period of 13 months.[1] This estimate is based on determinations made on 40 or more samples collected at different times throughout the year. By evaluation of the different salt determinations according to the total flow for the period they are intended to represent, an average dissolved salt content in the river water for that year of 278 parts per million was obtained.

Analyses of a very complete set of samples of water collected from Owens River at the same station are also summarized [2] in a mean of thirty-six 10-day composite samples taken December 31, 1907, to December 31, 1908, which gives the mean salinity of the river water for that period as 339 parts per million. This shows a greater concentration of saline matter in the water in 1908 than in 1907, but discharge data show that the volume of river water during 1908 was only a little more than half that of the preceding year. To a certain extent, therefore, these factors compensate one another, so that the yield of saline material each year may be considerably more constant than might be at first assumed from a mere comparison of volumes of flow.

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[1] Los Angeles Aqueduct Third Ann. Rept., pp. 113–114, 1907.

[2] Van Winkle, Walton, and Eaton, F. M.; The quality of the surface waters of California: U. S. Geol. Survey Water-Supply Paper 237, p. 121, 1910.

The mean composition of the Owens River water for one year is shown in the following average:

Average saline composition of Owens River water at Charlies Butte, December 31, 1907, to December 31, 1908.

[Walton Van Winkle and F. M. Eaton, analysts. Percentage of anhydrous residue.]

SiO_2	12.37
Fe_2O_3	.09
Ca	8.92
Mg	3.45
Na+K	19.83
CO_3	29.84
SO_4	15.53
NO_3	.48
Cl	9.49
	100.00

Total solids, 339 parts per million.

As usual in this method of expressing analytical results, the bicarbonate of the original river water is reduced to the equivalent carbonate in the expression as the anhydrous residue.

Estimates of the total amounts of the various saline constituents contributed to Owens Lake by Owens River are not particularly significant in the present study, for the salts dissolved in the water of the stream, where they exist usually in very dilute solution, undergo many changes on mixing with the standing and more strongly concentrated solution in the lake. Bicarbonate from the river water is partly changed to carbonate, especially in the presence of calcium and magnesium, with which some of it is precipitated in the form of less soluble salts and is included in the silt on the bottom. Silica also is partly deposited. Under certain conditions sulphate is partly reduced to sulphide by organic matter, and this may be taking place to some extent in the muds on the lake bottom, although in the main the loss of sulphate from the solution is believed to be due to the formation of less soluble minerals. Nitrates are relatively unstable when exposed, being peculiarly subject to the action of organic agencies. Potassium has long been known to be taken up and removed from solution by muds, soils, or clays, which have a very important power of absorption for that element. It is generally believed that potassium progressively disappears from the water throughout the silt-laden course of the stream and that this action continues after the solution enters the standing water in the lake. This very important factor with reference to the occurrence of soluble potash salts as a product of such saline concentrations will be given fuller consideration later. (See pp. 321-323.) As a result of these changes the salts that accumulate in the lake water are not by any means the sum of the constituents brought in by the tributaries.

Two radicles, however, seem more likely to accumulate and remain in solution under the conditions above described, namely, sodium and chlorine, and the annual amount of these two substances brought into Owens Lake by Owens River may be estimated from the data quoted for the year 1908. The total discharge for 1908 at Charlies Butte, the station where the samples for analysis were taken, was 218,000 acre-feet. From this it is calculated that at least 17,000 tons of sodium[1] and 9,500 tons of chlorine were contributed that year to Owens Lake by Owens River. These figures represent the soluble mineral content of the water that passed Charlies Butte that year, and not necessarily the total mineral content of the river as it enters the lake. Unfortunately no such comprehensive data are available for a lower station, and it is not known just what relation the figures given would bear to the discharge of salinity of the lower river. Another factor undoubtedly merits careful consideration in the refinement of such calculations as are here given, namely, the influence that modern irrigation may have had on the salinity of the river flow or on the composition of the lake. It is likely that the influence of this factor would be difficult to determine exactly.

If estimates of this sort are to be carried out with a greater degree of refinement, it would doubtless be better to use figures for average discharge over a number of years for computing the amount of denudation, because the variation in discharge is greater than the variation in content of dissolved salts.

GEOLOGIC AGE OF OWENS LAKE.

The idea of calculating the age of a landlocked lake from an estimated annual rate of accumulation of its dissolved saline constituents is not new.[2] The results thus obtained can not be considered wholly satisfactory, for in spite of certain factors that may be quantitatively measured there must always remain other essential factors which can not be exactly determined and which must rest largely on assumption. The total volume of Owens Lake, its composition, and the quantity and composition of its inflowing waters are now known with a considerable degree of exactness. It has already been stated that the total chlorine content of the lake waters is approximately

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[1] Sodium is assumed to be 17 per cent of the anhydrous residue in the analysis, in which sodium and potassium are reported together.

[2] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 255-258, 1890. Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U. S. Geol. Survey Mon. 11, pp. 226-227, 1885.

40,000,000 short tons. If the annual contribution of chlorine from the flow of Owens River has been 9,500 tons, it has required 4,200 years for the accumulation of this total amount of chlorine.

By similar reasoning the total sodium content of the lake waters is 60,000,000 tons. If the annual contribution of sodium from inflowing waters is 17,000 tons, this represents some 3,500 years of accumulation.

If such computations were worthy of even greater degree of refinement allowance might be made for the total quantity of the elements that may have been contained in the lake waters when the lake last ceased to overflow. In a rough way, however, it may be assumed that the figures given represent the time occupied by the last stage of the lake history—namely, that since water last ceased to overflow—during which the waters have by accumulation and evaporation concentrated the more stable dissolved constituents at a fairly definite annual rate. Although when the lake expanded to the maximum of two and one-half times its present evaporating surface the volume of flow in the river was doubtless at least two and one-half times its present flow, there probably was then a diminution in the relative proportion of dissolved salts in the waters contributed.

SUMMARY.

In the foregoing pages the character of the Owens Lake basin and the composition of its river and lake waters have been discussed. During an undetermined though probably a very considerable period Owens Lake overflowed. One period of overflow is probably to be correlated in time with the general expansion of other inland lakes in the Great Basin, such as Lakes Lahontan, Bonneville, and Mono, with which, however, it had no direct connection. While the overflow continued the waters in the lake were comparatively fresh, being derived from melting snows and ice fields, chiefly of the Sierra Nevada. Saline material derived from rock decomposition within the tributary drainage area was carried forward with the more abundant water supply in the same way that it is carried in Owens River water to-day. Since the final cessation of the overflow from this basin, brought about perhaps by a gradually diminishing water supply, concentration by evaporation of the river waters has been going on. The result has been the accumulation in Owens Lake of a great quantity of soluble saline material. The length of time it has taken to accomplish this accumulation is in very general terms about 4,000 years, or possibly considerably less. This period also includes the final desiccation and subsequent alluviation in the other lake basins in the Owens-Searles-Panamint drainage system. Consideration of the further evidence afforded in these other basins follows.

SEARLES LAKE.

GENERAL FEATURES AND HISTORY.

Searles Lake or Marsh, also known as Slate Range Marsh and Borax Flat, is a dry lake basin, superficially much like many other desert basins of the western arid region of the United States. These names, as generally applied, refer to the broad, flat salt-incrusted surface in the center of the desert basin, although, except as it is intermittently flooded by shallow waters, the region strictly does not contain a lake at all. The basin in which Searles Lake is situated seems to have no generally accepted name but will here be designated the Searles Basin. It is a broad, roughly circular valley or depression 8 to 10 miles from east to west and 20 to 25 miles from north to south, bordered by the abruptly rising slopes of the surrounding mountain ranges. This basin lies between the Argus Range on the west or northwest and the Slate Range on the east, the latter a narrow rocky wall which divides it from the larger and deeper depression of the Panamint Valley. The camp at the old soda works in the Searles Basin is in the northwest corner of the main desert flat, some 25 miles by road from Searles post office, formerly Garden Station, an old stage stop of the overland route through this part of the desert country. Garden Station is now only about a mile east of the branch line of the Southern Pacific Railroad. Searles Lake has been reached by the regular stage that runs from Johannesburg via Garden Station, or Searles, to Searles Lake, and thence on to Ballarat and Skidoo, and passenger traffic doubtless still goes this way, although the branch railroad is now completed, connecting the Searles basin with the Southern Pacific main line.

The Searles Basin was, during a part of the glacial epoch, occupied by at least one deep lake whose traces are still so distinct as to be indisputable. While the waters stood at their highest position the Searles Basin was flooded to a depth of 635 to 640 feet above the level of the present valley bottom and the lake extended back through the Salt Wells Valley to join with a broad, shallow lake that flooded the greater part of the Indian Wells Valley. With the lowering of the water level less than 75 feet the divide in the volcanic peaks between Indian Wells Valley and Salt Wells Valley became an actual division between two distinct water bodies, and for a time here also there was a period of overflow from Indian Wells Valley to the lower waters in the Searles Basin in the same way that Owens Valley overflowed and spilled its waters into Indian Wells Lake. These are facts attested by the records of the ancient shore lines and water channels.

Horizontal beaches and shore markings over the more rocky portions of the marginal slopes show with great distinctness around the present valley, being preserved in certain localities much more clearly than in others and having been practically removed in still other parts by recent erosion. The old shore lines are more or less marked with deposits of calcareous tufa, in some places amounting to very considerable masses, resembling the tufa deposits of the Lahontan, Mono, and Bonneville basins, described by Russell[1] and Gilbert.[2]

The absolute elevation of a former temporary water line is very difficult to determine. Hence observations on the elevation of these shore lines can not be depended on within at least several feet. A number of spirit-level bench marks have been established by recent surveys for the more accurate determination of the height of the old shore lines. Although these figures show some slight variation, it may be no more than the latitude which should be allowed in the identification of the actual water level on the beach. These readings are as follows:

Elevation on uppermost shore level of the ancient lake in Searles Basin.

	Feet.
Permanent bench mark on upper shore in canyon 2½ miles northwest of old soda works and southwest of the tanks	2,255
Permanent bench mark in first large canyon on west side of the basin north of old soda works (not definitely known that this represents the actual shore level)	2,245
Temporary bench mark on highest bench on east side of basin, 7 miles east of the old soda works	2,262
Permanent bench mark in old channel of overflow at south end of basin (elevation of highest point in pass 2,264 feet)	2,262

The determined elevation of the lowest part of the present salt flat in the main Searles Basin being 1,617.6 feet, the maximum height of the former lake above the salt surface, as indicated by these readings, was 635 to 640 feet.

In this connection a barometric record of the benches on the slope of the Slate Range in the main basin east of the old soda works is of interest as showing the more permanent water levels marked during the recession of the waters.

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[1] Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U. S. Geol. Survey Mon. 11, 1885.

[2] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 1890.

Elevation of benches on slope of Slate Range.

	Elevation by barometric reading.	Height above salt flat.
	Feet.	*Feet.*
Edge of salt flat, northeast corner (above or beyond this is a rise over a deep sandy alluvial slope)	1,625	
A clear, bowlder-strewn shore terrace with scattered tufa	1,850–1,910	285
An indistinct beach line	1,965	340
Foot of distinct basalt bowlder wave-cut cliff. (The first distinct tufa-marked shore northwest of the soda works is at 2,035 feet, barometric reading)	2,000	375
Top of a second distinct wave-cut cliff (10 feet or more high), assumed to be a beach	2,050	425
Top of next minor wave-cut cliff, a fairly distinct terrace, assumed to be part of an old beach	2,080	455
Top of wave-cut cliff with very narrow beach back of it	2,115	490
Narrow bench	2,130	505
Narrow but distinct bench	2,160	535
Very minor bench	2,170	545
Top of small bench	2,180	555
Upper edge of highest and most distinct beach, at base of a marked wave-cut rock cliff 30 feet or more above and beyond this point. (The cliff may be the point determined by the topographic party, temporary bench mark 2,262 feet)	2,240	615

As indicated by this record, the topmost distinct water line is the most deeply cut, and as its elevation corresponds with the elevation of the outlet channel, this agrees well with the conception that the lake may have had a comparatively long period of overflow. The overflow undoubtedly ceased abruptly with the cutting off of the main water supply from the Owens Valley, if not before, and from that time on evaporation must have proceeded almost uninterruptedly until conditions somewhat like those of the present were established. Several of the lower water marks, such as those of the 375-foot and 415-foot levels, are very distinct, but no special significance can yet be attached to them. The outline of the 375-foot level is practically the 2,000-foot contour.

Calcareous tufa forms conspicuous deposits along several of the more distinct shore lines and coats most of the minor shore benches. It is evident that these deposits are built up from lime precipitated from the entering ground or surface waters, presumably deposited as these solutions became exposed to the air and mingled with the stronger standing waters of the lake. The Pinnacles, conspicuous tufa crags rising to a height of 100 feet or more at the southwest corner of the basin, were probably formed in a similar manner, perhaps by waters rising from springs along a fault zone at a time when the lake stood at one of its lower levels.

The tufa on the uppermost bench as observed in certain localities is a very irregular cellular mass, deposited as a coating below and extending up to the most distinct old shore line. Above this there is a well-marked wave-cut bench terminating against a cliff formed by wave plucking of the jointed volcanic rock. The tufa coating is spread over the angular talus blocks, which lie distributed in a broad band below the old beach. Many of these blocks are perched in insecure positions, except that they are in part held in place by the tufa coating acting as a cement. The attitude and character of these deposits suggest the comparative recency of their distribution and the deposition of the tufa, subsequent disintegration and erosion having affected the deposits but little.

The lower tufas are quite distinct in character from the upper, wherever they have been observed. In the gulch northwest of the soda works the lower tufas stand in pinnacles of tubular structure, like inverted stalactites, having a hollow or open, porous, stemlike form, or in forms not unlike the stems of a bluntly branching tree. It is assumed that these deposits correspond to the dendritic variety of tufa described by Russell as characteristic of the lower levels in the Lahontan Basin, occurring from the bottom up to an elevation 320 feet above the level of Pyramid Lake in 1882.[1] In the Searles Basin the tufa was in part apparently formed by rising solutions which followed fairly distinct channels and which deposited their lime below the then existing lake water level, perhaps most abundantly close to or below one of the more permanent water levels. Some of these inverted stalactites seem to have grown up within the sandy beach or delta deposits, as it is clear that they have since been uncovered by erosion. Their forms suggest that they are the deposits of seepage waters which presumably drained into the lake as its level lowered. Possibly the readjustment of the ground-water table to meet the lowering lake surface had something to do with a temporary excess of such seepage waters along the lake shores.

RELATIONS TO THE OWENS RIVER SYSTEM.

It has been explained that Owens Lake during a period of former greater water supply overflowed the divide at the south end of its basin and its surplus waters flooded in turn a succession of lower basins, of which the Searles Basin was one of the largest. The Owens waters after passing the Haiwee divide dropped some 1,500 feet in about 30 miles to Indian Wells Valley and there spread out in a broad and relatively shallow sheet of water. This in turn also overflowed, its water passing by way of Salt Wells Valley and a rock-cut gorge at the lower end of that valley into the Searles Basin. Eventually the waters rose in the Searles Basin to such a height that all three of these valleys were submerged in one continuous body of water. The maximum water level in this basin was clearly determined by the elevation of an outlet pass on the south side of the basin, whence its surplus waters flowed into the extreme south end of Panamint Valley. In the Panamint Basin a history similar in some respects to that of the Searles Basin was repeated. The waters rose until the

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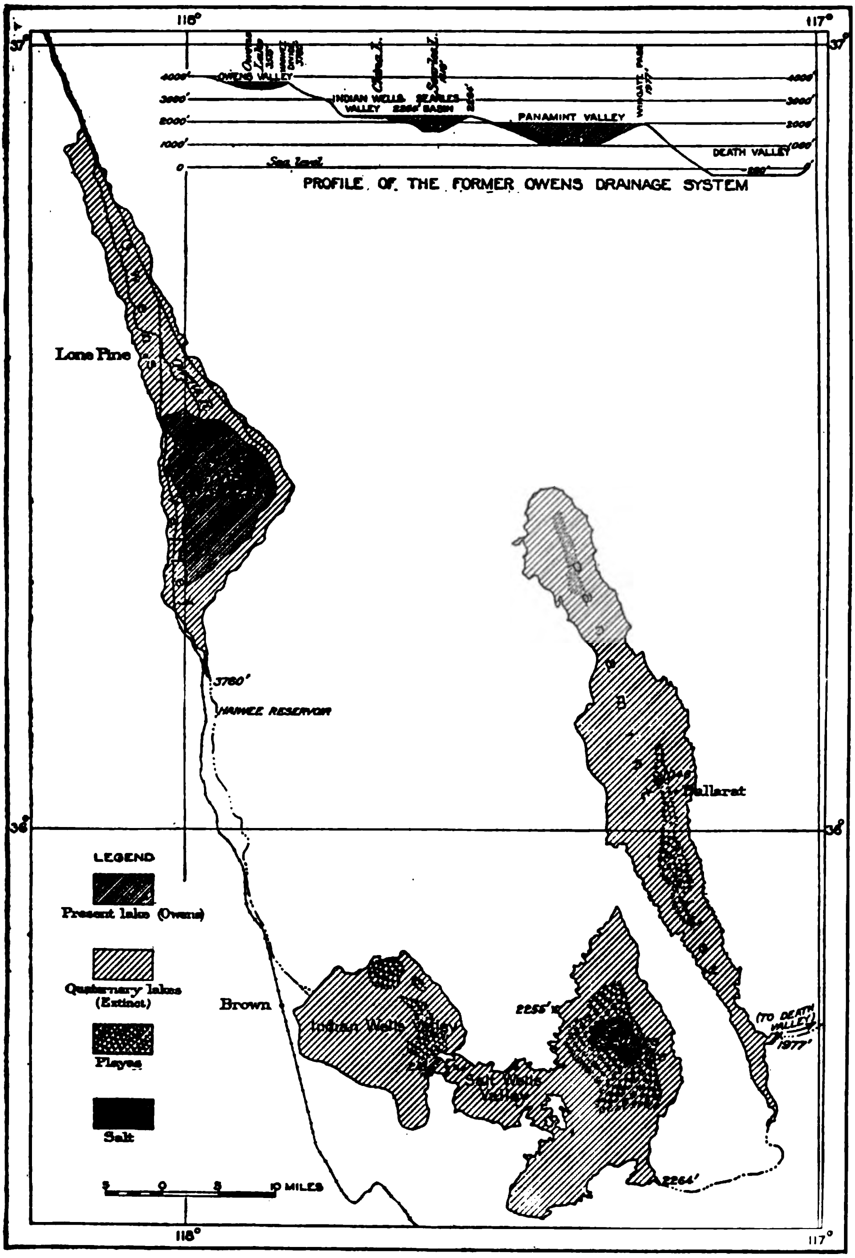
[1] Recent studies by J. C. Jones have led him to the conclusion, as yet unpublished, that the dendritic and lithoid tufas of the Lahontan Basin were deposited through the agency of algæ and perhaps associated bacteria. It is possible that further study in the Searles Basin would disclose a similar origin for a part of the tufa there.



MAP OF THE FORMER OWENS, SEARLES, AND PANAMINT LAKES, CAL.

height of the lowest outlet was reached, and as they evidently remained stationary at about that level for a relatively long period, it is presumed that this level was determined by the overflow of its surplus water.

The accompanying maps (Pls. V and VII) show the general relations of these lake basins. The record of these ancient lakes is found in various traces left in the present dry valleys. The discussion of this record, including especially the consideration of the saline deposits left by the evaporating water, is the principal object of this paper. Indian Wells Valley and Salt Wells Valley are first described in a general way, as these valleys were included in the greatest expansion of the ancient Searles Lake.

INDIAN WELLS VALLEY.

Indian Wells Valley, also known as Browns Valley, lies south to southeast of Owens Valley. It is a broad open stretch of country, mostly filled with a surficial deposit of heavy, deep, sandy soil, which through recent development of artesian and pumping wells seems to be giving considerable agricultural promise. As stated above, this valley was formerly a part of an extensive lake whose principal history is very closely linked with that of the deep lake of the Searles Basin. The inlet by which the waters from the Owens Basin enter lies in the northwest corner of the valley, and a channel of overflow to the southeast is found through the barrier of volcanic peaks that separates Indian Wells Valley from Salt Wells Valley.

The broad Indian Wells Valley is now filled deep with loose sandy materials—a veritable delta deposit. At the lower edge of the valley farthest from the inlet and nearest the outlet the lowest part of the basin is a typical mud playa known as China Lake or China Borax Lake. This name was given because of former borax workings which were presumably operated by Chinese labor. The playa surface is scarcely 30 feet below the low divide of the outlet between it and the Searles Basin. Thus, a rise of waters of more than 30 feet in the China Lake flat would cause an overflow through the pass into the Searles Basin, but there is no record that such an event has actually occurred within historic time. It is difficult to estimate the amount of the filling that may have taken place in Indian Wells Valley, or how deep the original lake in this basin may have been below the fill. However, it seems fair to assume that during the greater part of its history as a lake it served principally as a settling basin in which the sand and silt from Owens Valley and below were laid down as a broad delta deposit, so that the clarified water drained onward through the outlet on the opposite side. That the valley was thus filled nearly to its present level with sediments while the waters continued to overflow seems more likely than that this basin ever served as a concentrating reservoir. Certainly the configuration of the basin at the last of the lake periods, when it finally separated from the waters in Searles Lake, was practically what it is to-day, as is shown by the water lines still preserved in the sandy and alluvial slopes about its margin. Therefore the final lake in this basin probably was not much over 100 feet deep, although it was of broad expanse. The principal significance of the lake in Indian Wells Valley as a part of the system seems therefore to have been that here the bulk of suspended sand and silt was settled and only the clarified waters flowed on to the lower lakes. Possibly to this feature chiefly is due the freedom of the Searles Lake deposits from the admixture with muds that is characteristic of most desert salt deposits.

SALT WELLS VALLEY.

A smaller basin, known as Salt Wells Valley, constituted an arm in the ancient Searles Lake and in lower water stages formed the channel by which the Indian Wells Valley overflowed into the Searles Basin. It contains a small mud playa, but is in effect a part of the drainage area tributary to the present Searles Basin. Salt Wells Canyon, entering the main Searles Basin, is a gorge cut in granite and basalt. The channel was clearly graded to a steeper slope than that of the present stream channel. The rock-cut gorge is filled by sediments at its lower end, indicating that at some period its grade was directed to a lower level than the present surface of the deposits in the Searles Basin. This channel broadens as it approaches the Searles Lake playa, and the former gorge is filled with the pale-greenish, gently dipping or horizontally bedded lake-deposited clays or with sand and alluvial wash. This indicates that the former Searles Basin must have been far deeper than the present basin, a conclusion which is also borne out by the record of the deeper borings put down in the basin itself.

AREA AND VOLUME OF THE ANCIENT LAKE.

The area of the former Searles Lake at its greatest expansion, as indicated on the map (Pl. VII), was about 385 square miles. This includes both that portion which occupied the Searles basin and its extension into Salt Wells and Indian Wells valleys. At this time the level of the waters was evidently determined by the height of the outlet pass on the south side of the Searles Basin, by which the surplus waters found their way into the lower Panamint Valley.

The area and volume of the basin of this former lake have been computed from planimeter readings taken from the Geological Survey contour maps, and are tabulated herewith, the detailed figures being given also for their possible later use in other computations.

Area calculated for lakes at various elevations in the Searles Lake basin.

	Square miles.
2,255-foot contour (maximum water line)	384. 40
2,200-foot contour	275. 56
2,100-foot contour	197. 51
2,000-foot contour	165. 74
1,900-foot contour	130. 02
1,800-foot contour	110. 06
1,700-foot contour	85. 48
1,618-foot contour (elevation of salt flat)	11. 28

The volume calculations are made by assuming the whole basin to be divided into layers at the levels of the selected contours, the volume of each layer being computed from a modification of the prismoidal formula in the form $\text{volume} = 213\tfrac{1}{3}l(a+b+\sqrt{ab})$. The factor $213\tfrac{1}{3}$ is introduced to give the result in acre-feet; l is the vertical interval represented by the layer concerned recorded in feet, a the area of the top level in square miles, and b the area of the basal level in square miles. The results of these computations are in round numbers as follows:

Volume of separate layers in ancient Searles Lake.

Including contours.	Interval.	Volume.
	Feet.	*Acre-feet.*
2,255-2,200 foot	55	11,562,000
2,200-2,100 foot	100	15,069,000
2,100-2,000 foot	100	11,609,000
2,000-1,900 foot	100	9,441,000
1,900-1,800 foot	100	7,674,000
1,800-1,700 foot	100	6,241,000
1,700-1,618 foot	82	2,727,000
		64,323,000

This total is equivalent to more than 200 times the total annual discharge of Owens River into Owens Lake at the present time or 60 times the volume of Owens Lake but is not as great as the total volume computed for Panamint Lake at its highest recorded elevation.

THE SALINE DEPOSITS.

The most distinctive feature of this desert basin is the immense sheet of solid white salts that lies exposed in its bottom. It is to this salt deposit that the name Searles Lake (Searles Dry Lake) has generally been applied. So far as known at present the deposit is unique in this country in the variety of its saline minerals. The immense salt fields in Death Valley are less well known and doubtless contain a larger quantity of sodium chloride and possibly other minerals, but so far as known at present they seem to be of the ordinary playa type, and so of a somewhat different class from the Searles Lake deposits.

As in other desert basins the valley deposits in the Searles Basin may be distinguished as occupying several more or less distinct areas or zones. These are:

(*a*) The central area of firm crusted salt, constituting what is described hereafter as the main salt deposit. This is variously estimated at 11 to 12 square miles in area.

(*b*) The playa zone, including the central salt area and a broad surrounding margin of salt-incrusted mud and sand, bare of vegetation, composed of salts and mixed alluvial material washed in toward the center of the basin from the surrounding valley slopes. The area of the playa zone is roughly about 60 square miles.

(*c*) The alluvial slopes surrounding the playa zone, composed of detrital material washed from the surrounding mountains and spread out in broad, low, flat alluvial fans, the surfaces generally covered with scattered brush. The materials of which the alluvial slopes are composed are coarser nearer their source at the mountain front and grade off in fineness toward the center of the basin until they merge with the soils in the bare playa zone.

(*d*) The bare rocky slopes of the bordering mountain ranges, which lie beyond and above the alluvial fans and the steeper rock-talus slopes.

The area of salt crust in the Searles Basin is roughly circular as represented on the map, elongated slightly from northwest to southeast, and almost central in the basin. It is believed to be 11 or 12 square miles in extent, as determined by the private surveys and the drilling that has been done. Its surface is the lowest part of the basin and the elevation, determined by spirit leveling in connection with the preparation of the Geological Survey map, is recorded as 1,618 feet above sea level. In unusually wet seasons surface drainage from the surrounding country sometimes floods the salt surface to a depth of a few inches. Not uncommonly a thin sheet of water, flooded out upon the flat from some local storm, is swept across the surface by the force of the wind, so that perhaps nearly the whole mass of the water is moved from one side of the basin to the other. The surface salt is dissolved to a slight extent by these floods and when it again dries the salt crystallizes with a snowy whiteness that is exceedingly dazzling in the bright sun. Dust storms, which are common to this desert region, scatter more or less dirt over the salt crust and a certain amount of such material is thus almost constantly being mixed with the salt.

The surface of the main or central salt deposit is a firm crust of salt crystals, mostly cubic halite, so hard and compact that it will support the weight of a wagon and team or even the heavy drill rig. The surface shows a tendency to crack along irregular lines, so that it is divided into cakes or blocks. Flooding and resolution tend to level inequalities that arise and the cakes and fractures are not so pronounced a feature here as they are on some salt surfaces of similar type elsewhere.

The outline of this central solid salt area is probably not as definite as is indicated by the representation of it on the map, but it is given as interpreted from the borings that were first put down in testing these deposits. The depth of the salt is shown by the drillings to be fairly uniform and it is reported to range from about 60 feet to more than 100 feet, but probably averaging 70 to 75 feet in the main part of the deposit. In the central zone the proportion of mud layers found with the salt is comparatively small, so that the mass is in effect a solid body of salts. At and beyond the margin mud is found not only at the surface but intermingled with the salt deposits in depth, so that a sharp delimitation of the main salt deposit would probably be difficult. It is known, however, that the thick mass of solid salts is much more extensive than is indicated by the surface outline of the central salt area, and that a very considerable thickness of crystalline salts underlies a large area which is represented on the surface by playa mud and salt. Just how far this main salt body extends can of course be shown only by drilling.

The more solid part of the main deposit consists essentially of crystalline salts, in which more or less distinction by layers, from the bottom up, may be recognized, undoubtedly indicating the order of deposition in which the mass was originally laid down. This is a subject which will receive more extended consideration after the chemical data concerning the deposits have been reviewed. One of the wells drilled through the salt crust September 20, 1913, was carefully sampled, under the writer's direction, by W. B. Hicks, of the Geological Survey, and the samples are now on file awaiting mineralogic and chemical examination. All these samples consist mainly of crystalline salts more or less completely drained of the brine in which they were naturally immersed. A rough description of this record is as follows:

Samples from well 86, Searles Lake, Cal.

[Drilled September 20, 1913.]

No. of sample.	Character.	Depth.
		Feet.
1	Slightly muddy crystalline salts in coarse granular form, drained of the brine, apparently in large part halite in cubic crystals and broken fragments	0- 5
1a	Duplicate bottle sample containing selected halite crystals, showing development of octahedral forms. Crystals 1 inch or less.	
2	Clear to slightly greenish crystals drained of the mother-liquor brine, mainly showing distinct crystal forms of halite, both cube and octahedral. Coarser grained than No. 1, size of pea to ½ inch or more in diameter	5-10
2a	Duplicate bottle sample containing large, irregularly fractured or cleaved pieces of a clear-white saline, probably halite.	
3	Slushy sample consisting of salt crystals of distinct halite form ½ inch or less in size in finer granular mass of smaller crystals colored by a small admixture of dull greenish mud	10-15

Samples from well 86, Searles Lake, Cal.—Continued.

No. of sample.	Character.	Depth. Feet.
4	Similar in appearance to sample 3	15–20
4a	Duplicate bottle sample containing selected white to transparent crystal fragments from same zone.	
5	A mass of wet salt crystals, slightly mashed and colored by greenish mud, mostly showing some crystal outline, size of grains of wheat to size of corn	20–25
6	Similar to sample 5 but contains double-ended hanksite crystals with other salts	25–30
6a	Similar to sample 6, but hanksite less abundant. Some large dark distinct crystals, undetermined	30–32
7	Salt or saline crystals much bedaubed with dark-greenish to gray wet mud	32–35
8	Salt grains, crystals (halite forms), and a wet mass of finer saline material, somewhat crushed and mixed with mud	35–40
9	Clear, transparent salt grains, wheat size in general, including both coarser and finer material and some distinct hanksite crystals	40–45
10	Salt in coarse and fine granular and cubic crystal forms, with distinct hanksite crystals, all somewhat discolored by mud	45–50
11	Wet salts, granular and in coarser fragments, halite and possibly also other soda (?) minerals, clean from mud and drained of brine	50–55
12	Same as sample 11	55–60
13	White slushy mass of salts (as if coarsely ground up), containing some larger snowy-white and a few large, very dark crystals (?)	60–65
14	Same as sample 13, including a few dark crystals	65–70
15	Mostly opaque white mass of salts drained of brine, not mixed or discolored with mud; suggests soda carbonate, trona (?), with few granular fragments and crystals like halite, perhaps halite from upper part of well. This is reported to be the bottom of the salt deposit	70–75

NOTE.—These samples are perhaps not entirely representative of the strata at the recorded depths, as the drilling was done by means of churning with a tubular bucket, which had a flap valve and cutting shoe at the lower end, and casing was driven intermittently, so that there was more or less opportunity for sloughing of walls above into newly drilled salts below and thus of mixing the materials. However, the samples were very carefully taken and undoubtedly represent in the main and as well as could ordinarily be obtained the composition and variation of the deposit for the different intervals recorded. Unfortunately the pressure of other work in the chemical laboratory has prevented the detailed study of these samples, which will, however, undoubtedly be undertaken in due time.

The salt deposit is in effect a consolidated mass crystallized from an evaporating mother-liquor brine, in which the salts are still immersed, so that it represents a product of desiccating solutions of which the desiccation has not yet been carried to the final stages. Further evaporation of the residual liquor is checked below the reflecting white surface of the salt, and the influx of ground waters and the minor amount of surface waters from the slopes about the basin maintains the balance with evaporation. As a consequence the ground water or heavy saturated brine within the salt mass normally stands at or within a few inches of the actual salt surface. Within the salt mass below the surface the crystalline structure seems to be of such an open cellular or porous nature that the free movement of the ground liquors is not impeded to any considerable degree.

In connection with prospective utilization of the brine by pumping from this deposit attempts have been made to estimate the proportion of brine to solid crystal salts in the mass. The original estimate made in the Government announcement concerning the deposit placed the figure for the brine at 25 per cent by volume of the whole mass. More recent investigation seems to indicate that this figure was much too low. The data on which the later estimates are based are not yet available for quotation, but the interpretation given to them seems to be trustworthy.

The accompanying map (fig. 59) shows the location of the earlier holes that were drilled in the deposit, these being the basis for the outline given for the main salt deposit on the other maps. Many more wells, to the number of at least 200, have lately been sunk through the salt as far as the underlying mud, and these should give a much more complete record of the extent and character of the deposit.

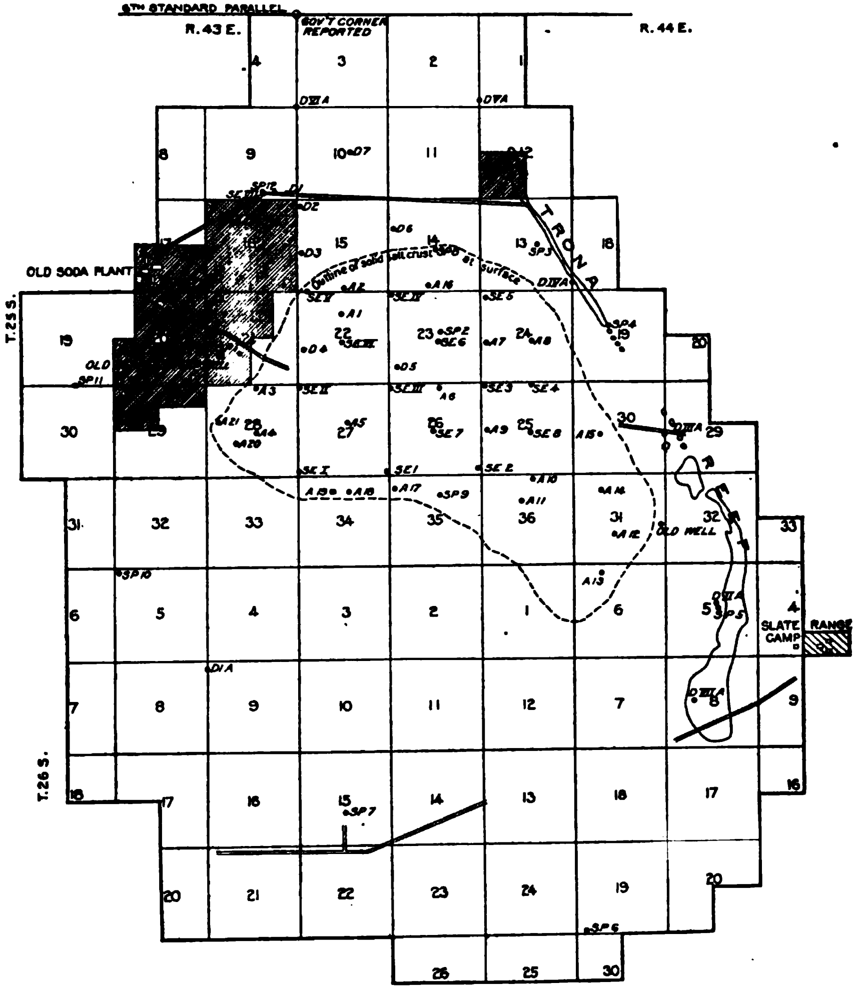


FIGURE 59.—Map of the salt deposit, Searles Lake, Cal., showing the "trona reef" and wells drilled prior to February, 1912. Based on a theoretical projection of the land survey net tied to a supposed Government corner on the north side. (Data derived from private surveys.)

The soft mud zone surrounding the main salt deposit contains a very large amount of saline material which doubtless also includes much crystalline salt. Its surface, when dry, is crusted with white salt and is not readily distinguishable from the more solid mass of the central salt area, but the proportion of mud mixed with the salts is very evidently greater toward the outer margins of the deposit. The marginal salt and mud zone rises slightly, in general only a few feet, above the level of the central part of the basin, and its surface is more irregular. It is saturated with a dense brine which makes much of the surface so soft as to be difficult or impossible to cross. The water is evidently seepage from the higher slopes surrounding the flat. The soft ground extends back until the increasing proportion of coarser material renders its surface sufficiently compact to remain firm.

CHEMICAL COMPOSITION OF THE SALINES.

The chemical composition of the salt and brines in the main deposit has been determined by numerous analyses, special attention having been given in the more recent investigations to the brine that permeates the whole deposit rather than to the salts themselves. For the brine these may be summarized in a fairly simple form by the quotation of a few representative analyses, as the composition shown throughout the deposit, whether in samples from different localities or from top to bottom at one locality, seems to be remarkably uniform. In the following table are given six analyses made by Walton Van Winkle, of the Geological Survey, from as many samples which were collected from different parts of the deposit:

Composition of brine from Searles Lake, Cal.

[Percentage of ignited residue. Walton Van Winkle, analyst.]

	Well "A 21."	Well "SP 9."	Well "SE 3."	Well "A 14?"	Well "SE 7."	Well "SE IV."
SiO_2	0.05	0.03	0.00	0.00	0.00	0.03
As	.06	.06	.05	.06	.06	.08
Mg	.00	.00	.00	.00	.00	.00
Ca	.00	.00	.00	.00	.00	.00
Na	33.37	32.57	33.16	33.92	33.23	32.90
K	6.53	7.27	5.98	5.54	6.29	5.69
CO_3	7.37	7.95	6.65	6.89	6.85	6.94
SO_4	12.00	12.49	13.41	11.89	13.79	13.00
Cl	35.97	35.53	36.50	37.13	36.40	36.79
B_4O_7	3.07	1.58	1.77	2.03	2.08	4.14
	98.42	97.48	97.52	97.46	98.70	99.57
Total salts (ignited residue, percentage of original sample)	33.48	33.94	33.30	32.96	33.21	32.88
Specific gravity	1.3002	1.3045	1.2969	1.2935	1.2959	1.2932

The location of all these wells is shown on the small map of the salt deposit (fig. 59, p. 275).

Each sample was collected by lowering a stoppered and weighted bottle to a depth of 35 to 40 feet in the brine and then, by means of a separate cord provided for the purpose, jerking out the stopper and allowing the bottle to fill.

The original brine contains a variable percentage of bicarbonate, which is converted to the carbonate form in the anhydrous residue and is so expressed.

Another analysis, made by W. H. Ross in the laboratory of the Bureau of Soils, Department of Agriculture, is probably the most complete statement on record as regards the composition of this brine. It represents the natural solution pumped from well "SE 7." It is given below, and for comparison is added the average of the six analyses already quoted, which corresponds very closely to it.

Chemical composition of salts dissolved in mother-liquor brine of Searles Lake, Cal.

	Average of six (Van Winkle).	Ross.
Total anhydrous salts (ignited residue)	33.30	[a] 32.85
Specific gravity of brine	1.2974	
Composition of salts (as per cent of anhydrous residue):		
Na	33.19	33.57
K	6.22	6.06
Li		.01
Mg	.00	Trace.
Al_2O_3		.012
Fe_2O_3		.003
SiO_2	.02	.028
Cl	36.39	37.02
Br		.094
I		.004
SO_4	12.76	12.96
CO_3	7.11	6.70
PO_4		.30
As_2O_3	.06	.063
B_4O_7	2.45	3.00
	98.20	99.839

[a] Approximate, the specific gravity of this sample not having been determined.

The following notes are added to Mr. Ross's analysis:

Rb, Ba, NH_4, NO_3, Ca, Mn, Cu, none.
Loss on ignition, 0.69 per cent water and organic matter.
Sodium carbonate, 3.04 per cent in original solution.
Sodium bicarbonate, 0.75 per cent in original solution.
Potassium, 2.17 per cent in original solution.

The average analysis has been recalculated to the form of hypothetical anhydrous salts which might be derived from such a brine, as follows:

Hypothetical average composition of anhydrous residue of brine from Searles Lake.

Sodium chloride (NaCl)	51.61
Sodium sulphate (Na_2SO_4)	19.22
Sodium carbonate (Na_2CO_3)	12.79
Sodium biborate ($Na_2B_4O_7$)	3.23
Potassium chloride (KCl)	12.07
Sodium arsenate (Na_3AsO_4)	.17
	99.09

The composition of the salts has been given by private analyses, made during the testing of the deposit for soda and borax, as follows:

Analyses of samples from well "SE 8," Searles Lake, Cal.

Depth.	Insoluble, mud, etc.	NaCl.	Na_2SO_4.	Na_2CO_3.	$NaHCO_3$.	NaB_4O_7.	H_2O.
Feet.							
0-18	0.2	79.7	7.6	3.2	0.0	Trace.	3.3
18-25	1.4	44.0	30.5	14.8	2.5	1.0	5.8
25-30	1.4	47.3	28.1	10.6	.0	2.0	10.6
30-35	3.0	42.7	17.1	19.1	5.9	2.0	10.2
35-50	1.4	43.5	22.3	9.5	2.5	5.5	15.3
50-65	Trace.	82.8	10.6	3.2	.8	Trace.	2.6
65-79	Trace.	10.0	7.3	40.3	18.5	.5	14.4

Well "SE 8" is 1 mile due east of well "SE 7," of which the complete brine analysis is given above, and both are situated near the center of the main salt deposit. (See fig. 59.)

In these analyses potash was not determined, and presumably it is expressed as soda in the various combinations given. A single analysis showing the potash content of the salts is quoted on page 311.

The accompanying diagrams (figs. 60–74) represent graphically the variations in composition of the salts at the various depth intervals throughout the deposit. These diagrams are based on analyses of samples of salts from the borings, exclusive of the mother-liquor brine. The sites of the wells are represented on the map (fig. 59). The analyses themselves are not quoted in detail, the diagrams serving better to bring out the general significance of the results. The analyses were made by private chemists.

The diagrams are arranged roughly in geographic order, those from the center of the main deposit being placed first, followed by those to the south, to the southwest, and so on, completing the circuit of the deposit by way of the north and east.

Several noteworthy features are brought out by a comparison of the well records. One of these is the relatively inconsiderable percentage of the insoluble portion (sediment) in the main salt deposit, particularly at the center. This holds true even for the western and southwestern parts, opposite the mouth of Salt Wells Canyon, which would naturally be considered as one of the most likely sources of sediment during the formation of such a deposit. It is to be noted, however, that the outline of the main deposit as here represented is somewhat concave toward the mouth of Salt Wells Canyon and that the borings do not in fact represent any part closely adjacent to that side of the basin, and the delta may in fact be developed on that side, although it did not extend into the center of the basin during the period of salt deposition.

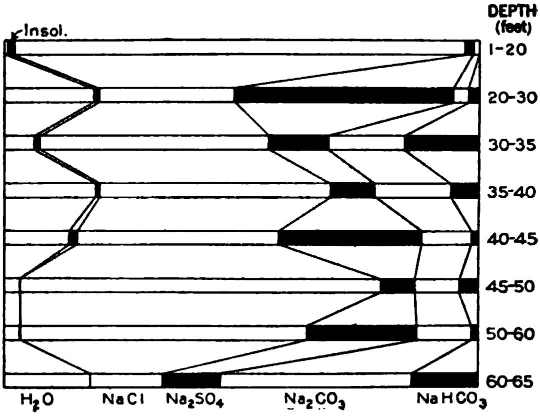


FIGURE 60.—Diagram showing variation in composition of salts at different depths in well "SE 3" (near center of main salt deposit).

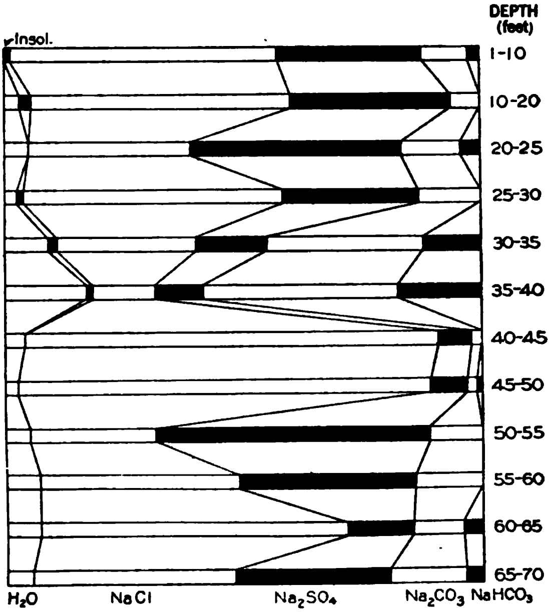


FIGURE 61.—Diagram showing variation in composition of salts at different depths in well "SE III" (near center of main salt deposit).

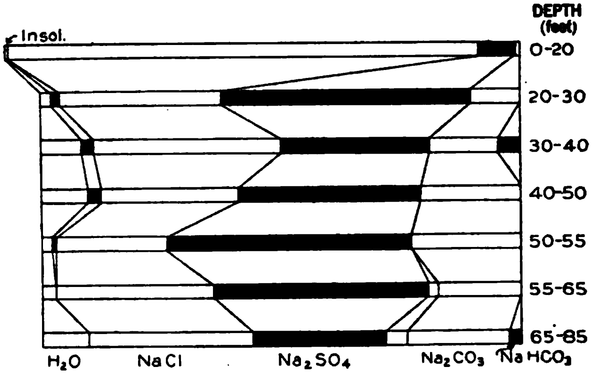


FIGURE 62.—Diagram showing variation in composition of salts at different depths in well "SE 7" (south of center of main salt deposit).

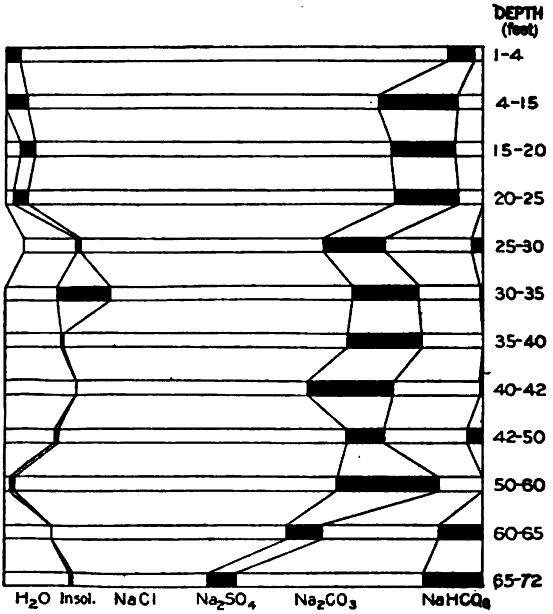


FIGURE 63.—Diagram showing variation in composition of salts at different depths in well "SE 1" (near middle of south side of main deposit).

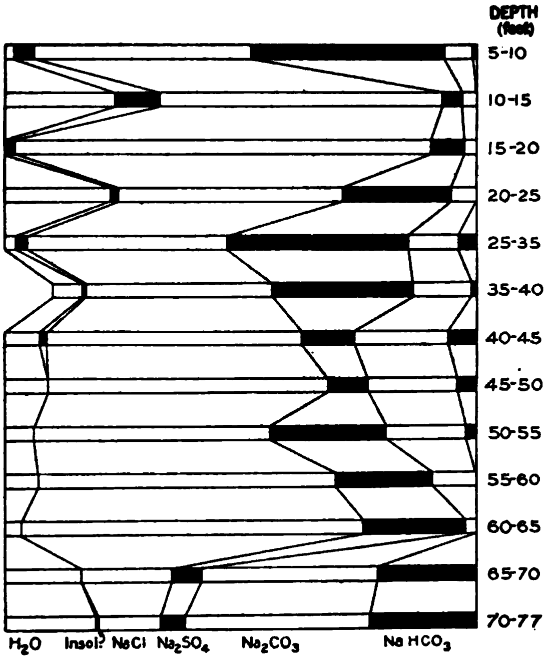


FIGURE 64.—Diagram showing variation in composition of salts at different depths in well "SE 2" (near middle of south side of main deposit).

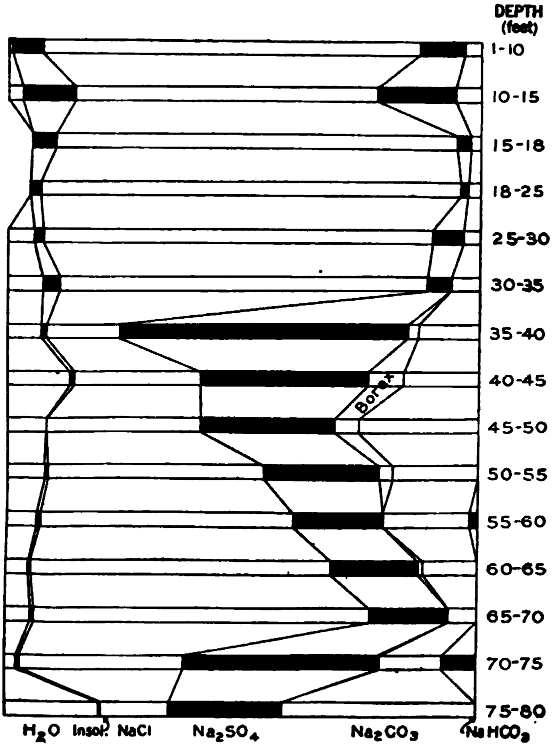


FIGURE 65.—Diagram showing variation in composition of salts at different depths in well "SE 1" (southwestern part of main deposit).

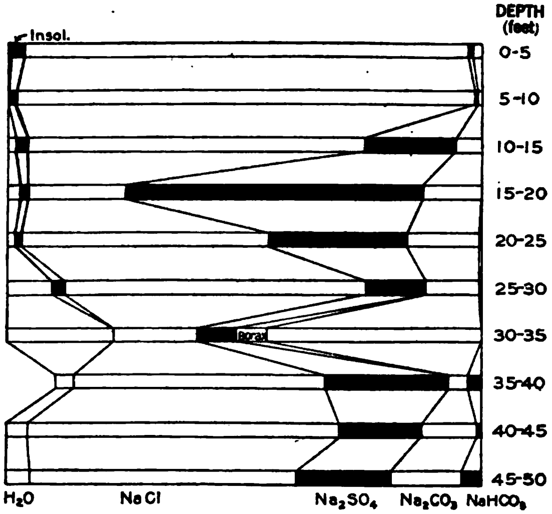


FIGURE 66.—Diagram showing variation in composition of salts at different depths in well "SE II" (western part of main deposit, close to edge).

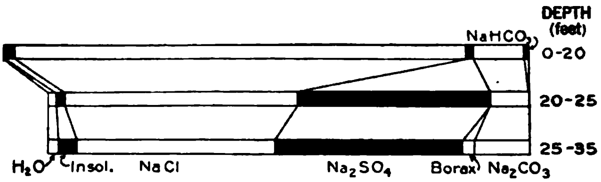


FIGURE 67.—Diagram showing variation in composition of salts at different depths in well "SE VI" (northwestern part of main deposit). This well evidently did not penetrate the whole thickness of the salts.

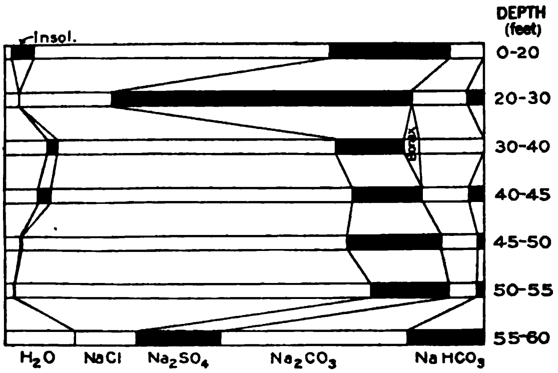


FIGURE 68.—Diagram showing variation in composition of salts at different depths in well "SE V" (northwestern edge of area indicated as main deposit).

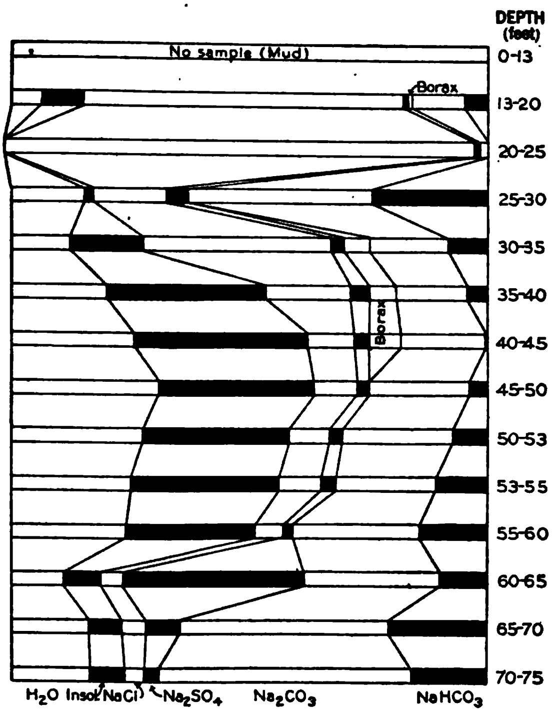


FIGURE 69.—Diagram showing variation in composition of salts at different depths in well "SE VII" (northwestern part of main deposit, outside the mapped area of the surface salt crust).

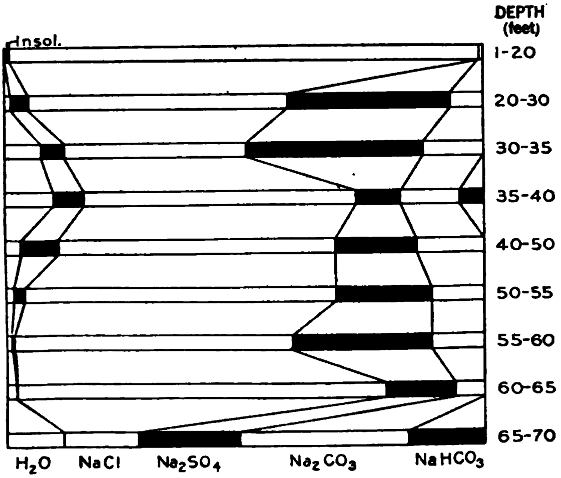


FIGURE 70.—Diagram showing variation in composition of salts at different depths in well "SE IV" (northern part of the main deposit).

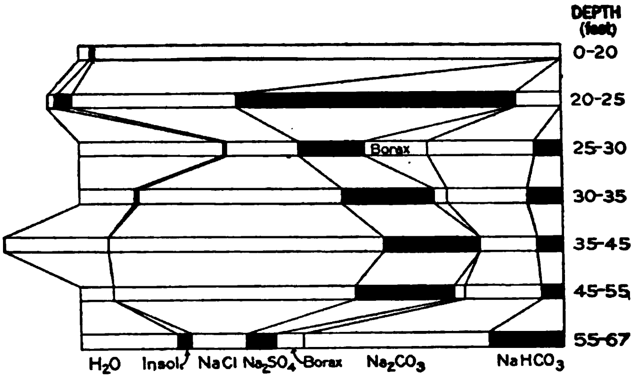


Figure 71.—Diagram showing variation in composition of salts at different depths in well "SE 6" (a little north of the center of the main deposit).

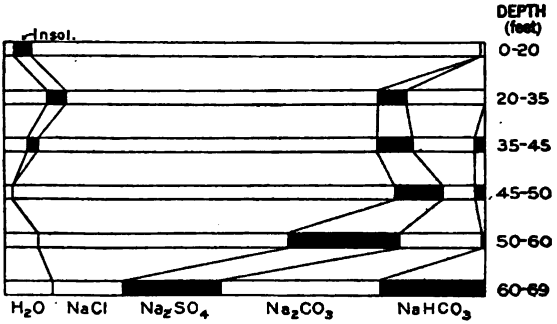


Figure 72.—Diagram showing variation in composition of salts at different depths in well "SE 5" (northeastern part of the main deposit).

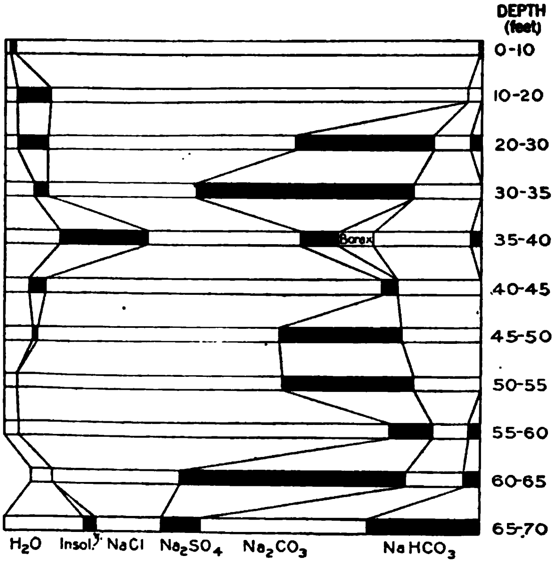


Figure 73.—Diagram showing variation in composition of salts at different depths in well "SE 4" (middle of east side of main deposit).

A most significant feature with reference to the chemistry of the deposits is found in the predominant deposition of sodium carbonate and bicarbonate in approximate "trona" proportions at the very bottom of the deposit. Comparison of the diagrams shows a subordinate recurrence of a similar stage at depths of 30 to 40 feet in the central part of the deposit, together with an increase in the amount of sediment (insoluble) contained and apparently a concentration of the borax at or about this general position. It is not shown by this record, but may be noted here, that the mineral hanksite and individual borax crystals, also probably sulphohalite, likewise characterize this zone. This evidence may indicate a temporary interruption of the general process of evaporation during the period while the salt deposition was going on.

The records from wells about the different parts of the margin show greater variation. There is commonly an increase in the amount of included sediment at various depths. Possibly some parts of the deposit are richer in borax than others. The principal point that appears to be emphasized, however, is the deposition of the carbonate and bicarbonate at the base of the deposit, and the relation this bears to the evaporation experiment to be referred to presently. There is a relative increase in the sodium sulphate in the upper parts of the deposit and apparently a concentration of sodium chloride at the very top.

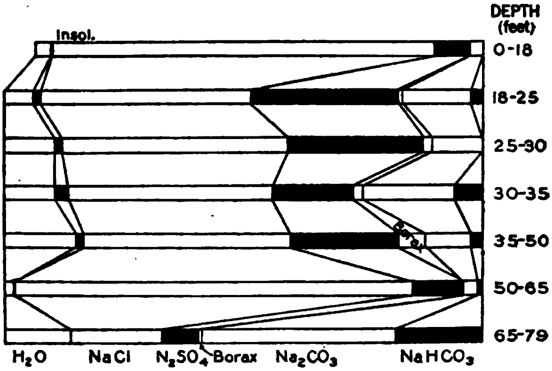


FIGURE 74.—Diagram showing variation in composition of salts at different depths in well "SE 8" (middle of eastern or southeastern part of main deposit).

The experiments of Chatard[1] are particularly significant in considering the origin of the salt deposits at Searles Lake. They are believed to show that these deposits are the normal product of the desiccation of a body of water of the same chemical character as the Owens Lake of the present time. There can be little doubt that such waters are primarily the product of the concentration by evaporation of the natural surface drainage waters of this region.

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[1] Chatard, T. M., Natural soda; its occurrence and utilization: U. S. Geol. Survey Bull. 60, pp. 59-67, 1890.

Chatard's experiments were conducted at Owens and Mono lakes in the summer of 1886. In these experiments measured quantities of the lake waters were set out in the open air, in receptacles, so that they might evaporate under essentially natural conditions. The volumes of the solutions were measured as they diminished, and temperature and specific gravity were determined from time to time. When deposition of the dissolved salts began, records were made, and with the development of a considerable crust or deposit the supernatant liquid was transferred to another vessel, where evaporation was again allowed to proceed. The crystalline residues were preserved for analysis. In this way the various stages of crystallization were recorded in the analyses that were obtained. In order to facilitate comparison the results of two sets of these determinations are plotted graphically in figures 75 and 76.

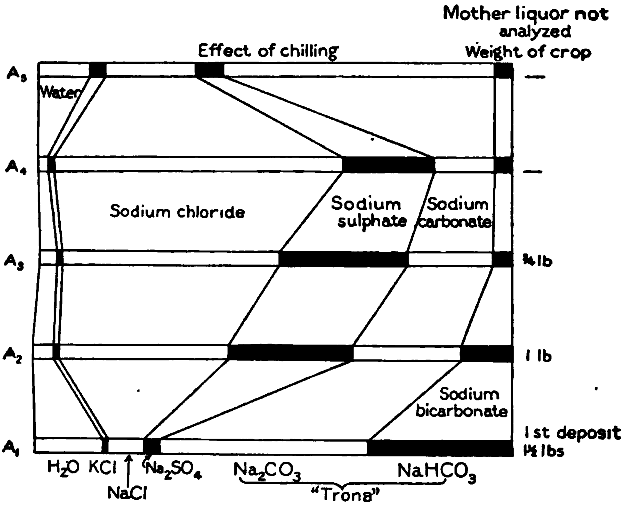

FIGURE 75.—Diagram illustrating graphically the results of Chatard's experiments with the evaporation of water from Owens Lake, Cal. A_1, A_2, etc., are numbers used in Chatard's tables.

The principal features brought out by these experiments are the early deposition of the sodium bicarbonate, the almost continuous deposition of the carbonate, the lag in sulphate deposition with a tendency to concentration at an intermediate stage of the process, and the progressive increase in deposition of sodium chloride during the normal open-air evaporation of the solutions. Precipitation of the carbonate by chilling and presumably also of the sulphate at earlier stages by unusual chilling suggest variations of the order as worked out for normal conditions. In each experiment the final step was one involving an artificial condition, being the complete evaporation by artificial heat in the experiments with the Mono water and the unusual chilling of the solution in the experiments with the Owens water. Therefore the significance of the top members of the diagram has to be read separately.

The following is a summary of Chatard's results approximately as stated by himself:

First. A deposition of calcium carbonate, beginning when the liquid has reached a specific gravity of 1.096 and attaining a maximum at 1.130–1.138.

Second or "trona stage." Incipient crystallization of the more soluble constituents, beginning when the solution has reached a concentration of 1.260, a distinct crust of salts being formed at 1.273. After a stout crust and considerable deposit of salts had formed, analysis proved it to be chiefly trona, $Na_2CO_3.NaHCO_3.2H_2O$, as indicated in the diagrams.

Third. The formation of a product consisting in great part of sulphates and chlorides.

Fourth. The production of a mother liquor requiring an artificial heat for its further evaporation, but rich in Na_2CO_3 and containing the major portion of the potash and boric acid.

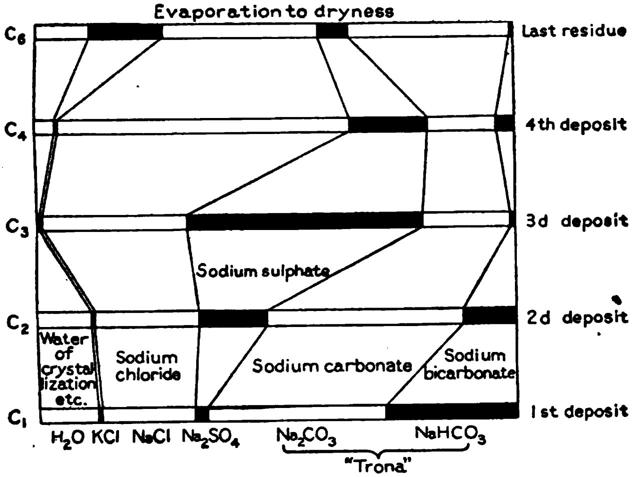

FIGURE 76.—Diagram illustrating graphically the results of Chatard's experiments with the evaporation of water from Mono Lake, Cal. C_1, C_2, etc., are numbers used in Chatard's tables.

Unfortunately, Chatard seems to have left no record of any analysis of the final mother liquor obtained in his Owens Lake experiment, although for present considerations this is one of the most interesting of the various products, containing, as he says, the major part of the potash and boric acid salts from the original solution. A record of the final stage was obtained in the experiment with Mono Lake water.

A comparison of Chatard's experimental results with the records of composition in the Searles salt body can leave little doubt as to the manner of origin of the Searles deposit. The record of the first or calcium carbonate stage in the Searles Basin is to be reviewed presently in a description of the deposits underlying the salts. The minerals found in the Searles Basin beneath the more soluble salts are more complex than the first granular precipitate obtained by

Chatard, suggesting some mineralogic possibilities that may not have been fully appreciated in the experimental work. The lower part of the main salt deposit at Searles consists of an opaque white granular mass, more or less caked as represented in samples, having the approximate composition of trona. This is with little doubt the representative of the trona stage. Subsequent deposition in the Searles salt mass was probably influenced more or less by periodic or other changes which can not be positively determined. However, it is fair to assume that the crystallizing process has now been naturally arrested somewhere within the third or sulphate-chloride stage, with the residual mother liquor being still retained beneath the salt crust.

Analyses of salt samples obtained from borings can hardly be expected to yield entirely satisfactory results. The salts are more or less mixed with and include the mother liquor, and the methods of ordinary drilling usually result in some mixture of salts, the upper being carried down and mixed with those below. Only general interpretations can be given to such results.

It has been explained that the residual mother liquor of the Searles deposit still constitutes a large proportion of the mass. It does not lie on the surface of the salts, as has so commonly been assumed for a desiccation deposit of this type. The whole structure of the crystallizing salt mass has been built up in a loose or open-texture manner, so that the residual liquors now permeate the deposit and are largely protected from further concentration by the reflecting surface of the salt mass. Searles Lake has not yet passed through the last stages of desiccation, nor is it likely that it would do so under the present climatic conditions. Evaporation at the surface is counterbalanced by percolation or seepage from the bordering slopes and the small amount of drainage water that still finds its way in on the surface. The composition of the mother liquor may therefore have remained as at present for a long period.

DEPOSITS UNDERLYING THE SALT.

The nature of the deposits underlying the salt mass is known chiefly from one deep well put down on the edge of the flat southeast of the old soda works and some shallower wells that have been sunk only a short distance beneath the salt. The record of the deep well was published in part[1] and has been extensively quoted, as the hole has been the source of a number of entirely new saline minerals, to which further reference is made in the following pages.

It appears from this record and the more complete data now at hand that the deposits that fill this basin below the mass of solid crystallized and more soluble salts are chiefly muds, which contain, however, a very considerable amount of chemically deposited material. These deposits may therefore be presumed either to have been laid down during the earlier stages of the former very much deeper Searles water body or to represent in part playa stages of the basin preceding the final lake history. The well record indicates that such deposits extended to a depth of 625 feet or more below the present valley surface. This record is unfortunately very incomplete. The first part of it, which has been published, is given herewith, supplemented by descriptions and records lately obtained from Mr. Dennis Searles, who with his father was associated in the work of boring the well and kept the log from about the 400-foot depth to the greatest depth reached, 627 feet 10 inches. The well record is probably now as complete as it can be made. It is supplemented by analyses and descriptions of the original well samples, most of which, preserved in glass jars, were found in one of the buildings at the soda works at the time of the writer's first visit to this locality.

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[1] De Groot, H., The Searles borax marsh, California: California State Min. Bur., Tenth Ann. Rept., p. 535, 1890.

Record of the Searles deep well at Searles Lake, Cal.

Date of drilling.	Sample No.[a]	Strata.	Thickness.	Depth.
			Feet.	*Feet.*
1887 [b]........	....	Salt and thenardite........	2	2
		Clay and volcanic sand, containing a few crystals and bunches of hanksite........	4	2-6
		Volcanic sand and black tenacious clay, with bunches of trona having black, shining luster, from inclosed mud........	8	6-14
		Volcanic sand containing glauberite, thenardite, and a few flat hexagonal crystals of hanksite........	8	14-22
		Solid trona, overlain by a thin layer of very hard material......	28	22-50
		Mud, black, soft, slushy, smelling of H_2S and containing layers of glauberite, soda, and hanksite; water has a density of 30° Baumé........	20	50-70
		Clay, brown, mixed with volcanic sand and permeated with H_2S. (At 300 feet "a hard streak of lime, mixed with alumina and silica; very strong test for borax")........	230	70-300
Sept. 12, 1895	1	Mud, fine, greenish (in the dry sample as preserved), filled with broken fragments of clear glassy pirssonite, which constituted the major portion of the sample saved, including also trona, some halite, and sand grains. (Sample marked 407 feet depth.) For further details see Mr. Larsen's report (p. 291)...	19	408-427
	2	Pirssonite, in broken fragments, as a fine clean glassy sand, this mineral constituting 90 per cent or more of the sample. Contains some northupite, halite, an unknown mineral called *a*, and sand grains. The northupite is in clear perfect octahedrons. Drill record says "crystal; drilling as hard as rock"...	15	427-442
	3	Pirssonite, in glassy crystalline fragments, mostly broken but some showing distinct crystal terminations, stained greenish with a small amount of mud or clay. This sample evidently represents a stratum encountered within the interval recorded. The mineral northupite is described as having been first found in clay at a depth of 450 feet in this well. E. S. Larsen reports as follows from an optical examination of this sample, "largely made up of pirssonite, and trona,[c] with some halite, northupite, unknown mineral *a* [see detailed microscopic report following this table], and sand grains." The northupite is in clear and perfect octahedrons........	27	442-469

[a] The samples have been examined microscopically by E. S. Larsen, U. S. Geological Survey, to whom most of the mineralogic determinations should be credited.

[b] Commenced in 1887, according to De Groot. The well was originally bored from the surface to a depth of 400 feet, but on account of the hole going crooked it was abandoned for a time.

[c] Some of this material selected by Mr. Larsen was analyzed by W. B. Hicks in the Geological Survey laboratory, showing, by quantitative analysis, CO_3, 24.6 per cent; HCO_3, 26.4 per cent. These results calculated to trona ($Na_2CO_3.NaHCO_3.2H_2O$)=95.4 per cent of the whole sample. By qualitative analysis, small amounts of Cl, SO_4, Mg, K, and insoluble matter present.

Record of the Searles deep well at Searles Lake, Cal.—Continued.

Date of drilling.	Sample No.	Strata.	Thickness.	Depth.
Sept. 12, 1895	4	Clay, fine, light-colored, powdery material according to dry sample, which, when examined under the microscope, proves to contain many small crystals of calcite. There is some halite, northupite, trona, mineral *a*, thenardite, and sand grains	*Feet.* 31	*Feet.* 469–500
Dec. 31, 1895	5	Clay, sample marked "Mud, green, with strong ammonia smell," recorded as from depth of 506 feet. The dry sample now on hand is a light-greenish clay filled with pirssonite fragments. Microscopic examination shows that the sample is about three-fourths pirssonite, with halite, northupite, thenardite, mineral *a*, claylike material, and a very few sand grains	15	500–515
Jan. 7, 1896	6	Clay, light brownish in dry sample now on hand, containing various insoluble mineral grains. Microscopic examination shows a few grains of pirssonite, numerous crystals of calcite embedded in halite and minutely crystalline material, probably clay, and some sand grains (like No. 10). Log notes "Borax present from surface water, not from actual crystals".	5	515–520
		At 520 feet "A hard streak 3 feet thick, test strong in borax"		520
		At 527 feet "Water from this level crystallized large cube salt in abundance when left to stand. Water also when evaporated gave very strong test in borax"		527
Jan. 8, 1896	7	Clay; dry sample now on hand is light gray and contains crystals of calcite		535
	8	Shale; sample consists of several consolidated fragments, a massive aggregate composed chiefly of pirssonite, with some halite and trona, a very little sand and clay, and a few spherulites of searlesite (see specimen 9), the whole apparently representing a consolidated thin-bedded layer. Sample marked "Rimmings showing formation of parallel lines"		540
	9	Spherulites; small rounded grains of light-gray color, containing carbonates (effervescing with acid), with some grains of quartz, feldspar, etc. Mineralogically composed of searlesite in clusters of radiating fibers with calcite embedded in it. Sample marked "Washings from mud"		540
Jan. 13, 1896	10	Mud or clay, grayish, finely powdered in dry sample as preserved. Contains numerous crystals of calcite embedded in halite and a minutely crystalline material, probably clay, also some sand grains		575
Jan. 15, 1896	11	Clay, with a white limy appearance; light, finely powdered in dry sample as preserved; mineralogically like sample 10		580
	12	Clay finely pulverized; light gray in dry sample. Sample marked "Rimmings"; mineralogically like sample 10, but contains more sand grains and a few larger grains of pirssonite which might have been brought down from above	10	586–596
Mar. 5, 1896	13	Clay, light greenish gray; a dry powdery sample as preserved; mineralogically like sample 10		600
	14	Crystalline material marked "Crystal deposited by standing over night from water at 600 feet; source of water we presume 400 feet." Consists of a reddish granular and powdered crystalline aggregate colored by iron, perhaps from rusty well casing or tools, etc		600
	15	Crystalline material, apparently duplicate of above, marked "Crystal deposited by letting water from 600 feet stand." Is a reddish granular and pulverulent mass, about three-fourths thenardite, with considerable halite in clear grains, some grains of unknown mineral *a*, and a few grains of sand and iron rust		600
Mar. 9, 1896	16	Clay, in flakes of greenish color; under microscope is shown to be made up of calcite, halite, claylike material, and about 10 per cent sand grains. This sample is probably in large part of detrital material. Sample marked "Soft clay underlying hard streak"		620
	17	Mud, dried in sample as preserved, containing carbonates and grains of other minerals. Marked "Deep well, Mar. 9, 1896. Soft clay overlying at hard streak 25 feet"		625
	18	Mud, described in well log as "fine-grained black and gray"; sample is now dry and in finely powdered state. Log records "Black and gray mud taken from deep well at 627 feet. Black turns gray on exposure." Microscopic examination gives results similar to those on sample 16		627
	19	Clay; sample as now on hand is fine greenish-gray pulverulent material, which under the microscope appears to be mainly clay containing calcite and halite, as in sample 16, but with a larger percentage of sand grains		$627\frac{10}{11}$

Mr. Dennis Searles states that—

In drilling the well a standard Pennsylvania rig was used. The tools were not the right kind for drilling in the lake. For instance, when the salts were hard the bit would first pound them to a powder, then pack them. When the bit broke through the hard strata it ran wild, as the mud, which was often 4 or 5 feet in thickness between the hard strata, allowed the bit to wobble and sink as though it were in water, with the result that when it struck the hard salt strata below the drill would glance and make a crooked hole. This resulted in our having to invent tools for doing the drilling. After the tools were invented our money gave out, as all told the drilling of the well cost about $30,000.

The mud from the lower part of the deep well was warm but not hot. My recollection on this point is very clear, as we used to "josh" and say that perhaps if we went deep enough it might get red hot. This may account for the rumors getting about that the mud was hot.

The report on the mineralogy of the samples from this well, by Esper S. Larsen, is as follows:

The material studied was powder immersed in oils of known indices of refraction and the minerals were determined by means of the petrographic microscope, supplemented by simple physical and chemical tests. The indices of refraction were measured by the immersion method, and the other optical properties were determined in the usual way. The greater part of the minerals were readily and positively determined by optical methods, but in some very fine fibrous minerals were not positively identified. No attempt was made to determine all the minerals present in small amount, as the material available was not thought to justify such exhaustive study.

Specimen 1.—Chiefly pirssonite with considerably less of unknown mineral *a*, trona, halite, and sand grains. Pirssonite makes up nearly all the grains which do not pass a 40-mesh sieve.

Pirssonite in clear crystals or in crystals dull from a coating of dusty minerals or from inclusions makes up the greater part of the sample, especially of the coarser part. Many of the crystals are pitted and rough, probably from corrosion. It has a vitreous luster, a conchoidal fracture, and the following optical properties: $\beta=1.510$; $\gamma-\alpha$, very strong; optically +; $2E$ = about 48°. Dispersion $\rho < \upsilon$ rather strong, Bx_a normal to tabular crystals. In part it is in good crystals of the habits figured in Dana's "System of mineralogy."

The powdery material coating the pirssonite and making up much of the fine material of the sample is greenish gray in color and is largely one mineral. Under the microscope it is seen to be an aggregate of minute fibers, some arranged in well-formed spherulites. They have a mean index of refraction of about 1.53, a birefringence of about 0.01, and negative elongation. They may be gypsum.

Trona is confined to the fine material and makes up only a small percentage of the sample. It is in rude lath-shaped or prismatic crystals with negative elongation and with Y emerging from the flat face. Its indices of refraction are: $\alpha=1.41$; $\beta=1.49$; $\gamma=1.54$. It is optically − and has a large axial angle. It is commonly embedded in the unknown mineral *a*.

Halite is present in the fine material cementing the other minerals. Isotropic: $n=1.542$. Tastes salty.

Detrital grains form only a small percentage of the material and occur only in the finer part. Chlorite, hornblende, quartz, plagioclase, orthoclase, etc., were recognized.

Specimen 2.—This sample is made up very largely of pirssonite with some northupite, halite, unknown mineral *a*, and sand grains.

The northupite is in clear and perfect octahedrons. It is isotropic and has an index of refraction of 1.515. The other minerals have their usual properties. The sand grains are microcline, quartz, plagioclase, chlorite, hornblende, etc.

Specimen 3.—Much of this material is in grains several millimeters across. The sample is made up largely of pirssonite and trona, with some halite, northupite, unknown mineral *a*, and sand grains.

The trona is in large crystal fragments which show one very perfect cleavage. In part they are clear and glassy, in part grayish and dull. They have the following optical properties: $\alpha=1.410\pm0.005$; $\beta=1.492\pm0.005$; $\gamma=1.542\pm0.005$. Optically $-$; Bx_a emerges normal to the cleavage. $\rho<\upsilon$ rather strong. $2V=76°$, computed from the values of α, β, and γ.

Specimen 4.—This sample consists chiefly of fine material, resembling that of specimen 10. The larger grains are mainly pirssonite. There is some halite, northupite, trona, unknown mineral *a*, thenardite, and sand grains of chlorite, feldspar, quartz, hornblende, etc.

Specimen 5.—This sample is about three-fourths pirssonite, with halite, northupite, thenardite, unknown mineral *a*, claylike material, and a very few sand grains.

Specimen 6.—Similar to No. 10. A few grains of pirssonite.

Specimen 7.—Similar to No. 10.

Specimen 8.—Massive fragment, mainly pirssonite, with some halite, trona, searlesite (see specimen 9), sand grains, etc. Part of this is similar to No. 10.

Specimen 9.—Chiefly spherulites of radiating fibers of the new mineral searlesite, with $n=1.525$ and birefringence about 0.01, 2V large, elongation $+$, and extinction not parallel. It has the composition $Na_2O.B_2O_3.4SiO_2.2H_2O$. Embedded in this are numerous crystals of calcite. There are very few sand grains.

Specimen 10.—Very fine grained. Numerous crystals of calcite embedded in halite and minutely crystalline material, probably clay. Some sand grains.

Specimen 11.—Similar to No. 10.

Specimen 12.—Similar to No. 10. More sand grains and a very few large grains of pirssonite (which might have been brought down from above during drilling?).

Specimen 13.—Similar to No. 10.

Specimen 15.—About three-quarters thenardite, with considerable halite in clear grains, some grains of unknown mineral *c*, and a few grains of sand and iron rust.

The thenardite has the following optical properties: $\alpha=1.464\pm0.003$; $\beta=1.474\pm0.003$; $\gamma=1.485\pm0.003$; optically $+$; 2V nearly 90°; $\rho>\upsilon$ perceptible. It is partly in large crystal grains, partly in aggregates of small grains.

The unknown mineral is in grains and aggregates of small grains. It has the following optical properties: $\alpha=1.445$; $\beta=1.482$; $\gamma=1.490$; 2E about 46°; $\rho>\upsilon$ moderate; optically $-$.

Specimen 16.—The sample is a very fine grained shaly material and is made up of calcite, an unknown mineral, halite, claylike material, and about 10 per cent sand grains. The calcite is in good rhombic crystals embedded in the halite clay and unknown mineral. The unknown mineral has a low birefringence and a mean index of refraction of about 1.53 and is probably optically $+$ with a large 2V. It may be gypsum or a kaolinitic mineral.

Specimen 18.—Similar to No. 16.

Specimen 19.—Similar to No. 16, with more sand grains.

The iron rust noted in the well record is doubtless derived from the casing or some tools or equipment used in the drilling. The principal feature brought out by the careful study of these samples is that they consist almost entirely of chemically deposited minerals, with a relatively minor proportion of detrital materials. While this is true of the specimens now at hand, there is some question as to whether such a generalization would hold for all the material that must have been removed by drilling. Interest in sampling naturally centered on the more unusual products, and some of the material, such as the spherulites of searlesite of sample 9, have the appearance of having been washed or panned to free them of any inclosing mud or admixed materials.

The halite noted in several of the samples may not be an original constituent of the material, as it is very likely to have been introduced by the use of the saturated surface brines for drill waters, and this may also hold true for other soluble constituents that have been determined—for example, some of the thenardite.

Aside from the incompleteness of the log and the possible inadequacy of the samples, the entire significance of this well record is difficult to interpret. The minerals pirssonite, northupite, glauberite, gaylussite, and others, to be described more fully later, belong to a class of the less readily water-soluble salines which might have been either deposited from saturated solutions in a concentrating lake or formed as layers more or less mixed with muds under playa conditions, where they were subject to alternate shallow inundation and desiccation. They undoubtedly belong to a class of minerals which are among the first to be deposited with the concentration of the waters, representing the forms in which principally the lime and magnesia are separated from the solution. Glauberite and gaylussite have been found in Columbus Marsh, Railroad Valley, and elsewhere in Nevada, where they were probably formed in muds as playa deposits, and glauberite has been found in Death Valley, Saline Valley, and elsewhere in California under similar conditions. The distribution of nearly all the minerals as more or less well defined, completely formed crystals embedded in mud, is suggestive of the playa mode of their formation, but it must be admitted that the evidence of the exact manner of their deposition is as yet very far from conclusive.

It is a most natural assumption that the less soluble minerals which seem to characterize the deposits underlying the salt to a depth of at least 540 feet and perhaps deeper may be the first products of deposition in the original concentration of the Searles Lake waters. Reasoning from Chatard's experiments suggests that they may thus indicate that stage in which the Searles waters first reached a density of about 1.1. It is also reasonable to suppose that a certain amount of sediment, such as silt or fragmental material or dust, would be more or less constantly entering the lake and settling with the minerals as they were deposited. Such a stage had probably already been passed through in the present Owens Lake when in recent years its water reached a maximum recorded density of 1.195. For this reason pirssonite and possibly also the other rare minerals might even now be recovered by dredging the muds at the bottom of Owens Lake. Conditions are not, of course, entirely comparable within these two basins, but the analogy is interesting. At any rate, it serves to indicate the rather likely possibility that the old Searles Basin, even during the later stages in the concentration of its waters, may have been considerably deeper than it is at present, and that it may have borne much the same relation to the whole drainage system that Owens Lake does to-day. If so, the desiccation of Searles Lake has been a long and possibly a frequently interrupted process.

THE "TRONA REEF" AND BORAX DEPOSITS.

Among the more superficial deposits of the region, one feature that deserves mention is the "trona reef." At the eastern and northeastern margins of the main playa zone rises a rim of crusted salts a few feet above the level of the flat and just at the foot of the alluvial slope of sand and coarser wash from the mountains. The deposit is of the nature of a saline efflorescence, being composed of salts brought up with rising ground water and deposited at the surface by evaporation. The "trona reef" at Searles Lake is one of the most massive deposits of this character that has been observed, although this feature is a common one about playa deposits generally, usually showing as a marginal rim of white efflorescent salts about the outermost edge of the bare, flat mud zone.

The position of the trona reef is indicated in figure 59 (p. 275). This was one of the features that first attracted attention to the Searles Lake deposits—in fact, a single tract of 160 acres at the north end is patented land originally taken up with a view to working these salts. The remains of a large steel-frame machine for hoisting and loading the salt still stand on the ground. The deposit is reported to consist chiefly of trona ($Na_2CO_3.NaHCO_3.2H_2O$), and it is presumed that the material was to have been utilized directly for the production of soda ash. That the trona should have been selectively crystallized in this zone is perhaps somewhat unusual but may be accounted for by supposing it to be a product pertaining to the second or trona stage as illustrated in the experiments on evaporation of the water from Owens Lake.

The composition of the "trona reef" is expressed in the following analysis, which was made by private chemists but is believed to be representative. It is an analysis of a composite of a number of samples taken from different points on the deposit.

Analysis of samples from "trona reef," Searles Lake, Cal.

Insoluble in water	13.33
NaCl	19.60
Na_2SO_4	5.05
Na_2CO_3	27.60
$NaHCO_3$	20.60
$Na_2B_4O_7$	1.52
KCl	1.50
	100.00

The composition of pure trona ($Na_2CO_3.NaHCO_3.2H_2O$) is:

Na_2CO_3	46.90
$NaHCO_3$	37.17
H_2O	15.93
	100.00

In the anhydrous salt the proportion $Na_2CO_3:NaHCO_3 = 55.79:44.21$. Thus the composition given for the trona reef allows for 46.6 per cent of the dehydrated trona, mixed with sodium chloride and other constituents.

Although surface drainage in this region is a relatively inconsiderable factor, the porous alluvial fill of the valleys constitutes an immense underground storage reservoir which is kept constantly filled. The outspread of material from the mountain slopes has been accomplished by the action of running surface waters. As is generally recognized, the coarser materials and the more steeply graded slopes lie next to the source of supply, and the materials grade off into finer deposits or alternating fine and coarse layers as they extend outward into the valley. A distinct and presumably steady movement of ground waters within these alluvial deposits toward the valley bottom is to be recognized in the shallow wells and the springs or marshy ground which they produce at the lower edge of the alluvial slopes. When this ground water encounters the saturated and less pervious deposits in the bottom of the basin its level rises. Where it does not actually flow out in springs, it lies so near the surface that moisture is constantly rising by capillarity. Its evaporation there produces the rim of salts so characteristic of the margins of many desert or playa deposits. The trona reef is a result of such influences.

Former borax workings about the basin were situated in the margin of the deposits in or near the zone of soft muds and rising ground waters. The mineral ulexite ("cotton ball") is said not to have been found in this deposit,[1] the borax having occurred in the form of natural sodium borate only. The "crude borax" at Searles Lake has been described as found on the surface of the "higher parts of the lake," presumably the slightly more elevated portions of the marginal playa mud zone, in a condition resembling burnt bone. Underlying this material, according to the description, was found a very hard, uneven deposit of different salts, which was generally not disturbed. The "crude borax" was collected to a depth varying from 2 to 8 inches.

There were at least two plants in the former borax workings, the old plant of the San Bernardino Borax Co. situated at the northwest corner of the flat, west of the soda works, and a smaller plant at the extreme north end of the flat, below the station now known as Tanks.

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[1] De Groot, H., The Searles borax marsh, California: California State Min. Bur. Tenth Ann. Rept., p. 537, 1890.

The reference by De Groot mentioned above is a description of the equipment and operations of the San Bernardino Co. The surface crust collected from the mud about the margin of the marsh was hauled to the reducing plant, where it was stored in a stack. The stacked material was thrown into dissolving tanks filled with the boiling solution and there kept until it was completely dissolved. Free ammonia is said to have been given off during this process. The heat was supplied through steam coils in the bottom of the tanks, the pipes being pierced with small holes to let off condensed steam. The hot solution, after standing eight hours to settle, was run into long wooden tanks where it cooled and crystallized. In five to nine days crystallization was complete, the product being borax of varying degrees of purity.

RED COLOR IN THE SALTS AND BRINE.

The surface salt and the strong brine standing in trenches or in pools about the margin of the salt deposit is characterized by a deep-red color, which is also imparted to some of the salt crystals at the surface of the deposit. The nature of this color has been discussed by Chatard and others, but the following quotation from Lunge[1] is perhaps the latest statement published with reference to its appearance in these particular deposits:

> The red color exhibited by many alkaline salt lakes, which is often also apparent in the salts deposited, is ascribed by Payen[2] to the presence of small crustaceans, *Artemia salina* Leach (*Cancer salinus* Linné), which appear in large masses when the water has attained a density of 1.16 and which are of a gray or greenish color; on further concentration to specific gravity 1.21 they die and form a red froth at the surface. * * * I, for my part, must decline to accept the assumption that the red color is regularly caused by the presence of Artemia or other animal organisms, if it is ever due to that cause; for the samples of red water which I had myself taken from the lakes of the Wade Atrun have preserved that color during the many years I have kept those samples. It remains after frequent filtrations. The red filtrate shows nothing under the microscope; the color is at once discharged by adding nitric acid or hypochloride and hydrochloric acid and is evidently caused by organic substances present in solution. There is no iron present.

MINERALOGY OF THE SEARLES LAKE DEPOSITS.

MINERALS CONTAINED.

Of the commoner minerals characteristic of desert-basin salines generally, probably the greater number are represented in the Searles Lake deposits, except ulexite, which is reported to be absent. The minerals found are included in the following list, arranged approximately, though not exactly, in the order of abundance. The list is not assumed to be complete, as the deposit has not yet been made the subject of a thorough mineralogic study and these minerals belong to a group which is not generally well known and whose recognition depends to a large extent on detailed chemical or optical mineralogic work. The solubility in water is indicated in the list.

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[1] Lunge, George, Sulphuric acid and alkali, vol. 2, pt. 1, p. 58, 1909.

[2] Annales chim. et phys., 2d ser., vol. 65, p. 156.

Halite	$NaCl$. Very soluble.
Mirabilite	$Na_2SO_4.10H_2O$. Very soluble.
Thenardite	Na_2SO_4. Very soluble.
Trona (urao)	$Na_2CO_3.NaHCO_3.2H_2O$. Readily soluble.
Natron	$Na_2CO_3.10H_2O$. Very soluble.
Borax	$Na_2B_4O_7.10H_2O$. Very soluble.
Gypsum	$CaSO_4.2H_2O$. Slightly soluble.
Anhydrite	$CaSO_4$. Slightly soluble.
Glauberite	$CaSO_4.Na_2SO_4$. Slightly soluble.
Hanksite	$9Na_2SO_4.2Na_2CO_3.KCl$. Readily soluble.
Northupite	$MgCO_3.Na_2CO_3.NaCl$. Slightly soluble.
Pirssonite	$CaCO_3.Na_2CO_3.2H_2O$. Slightly soluble.
Gaylussite	$CaCO_3.Na_2CO_3.5H_2O$. Slightly soluble.
Sulphohalite	$2Na_2SO_4.NaCl.NaF$. Slightly soluble.
Tychite	$2MgCO_3.2Na_2CO_3.Na_2SO_4$. Almost insoluble.
Searlesite	$Na_2O.B_2O_3.4SiO_2.2H_2O$. Almost insoluble.

Several other more or less common minerals, including celestite, cerargyrite, colemanite, dolomite, embolite, gold, niter, and sulphur have been said to be present in these deposits. The report covering colemanite seems to have originated in an article in the American Journal of Science, December, 1884, and is supposed to be an error or a misinterpretation, as colemanite is not known elsewhere in association with desiccation products in dry-lake basins. Niter has been reported in the clay hills at the south end of the Searles Basin, but not, so far as known, in any immediate relation to the main saline deposits. Calcite occurs in the sands of the deep well and in the tufa deposited on the old lake shores. Most of the other minerals reported, although doubtless found in the vicinity, are of doubtful significance in relation to the saline or dry-lake deposits.

The deep well at Searles Lake, which was begun in 1887 and completed in 1896 and the log of which has already been reviewed, has proved a veritable treasure house of unusual and entirely new minerals, including several that have never been found at any other place. The less soluble minerals were mostly found embedded in the muds or clay at the margin or underlying the main saline deposit. Several are characteristically found in small but distinctly formed crystals, many of which are unattached, as if they had grown within the mud. In places, however, layers of the crystalline material (as pirssonite) have become so consolidated as to present hard strata, offering considerable difficulty in drilling. Many of the specimens obtained as drill samples are fractured masses or even finely granulated material, but much perfectly preserved crystalline material has also been obtained in this way.

In the following pages is given a brief review of the more salient physical properties of these saline minerals. Acknowledgment is due to Mr. W. T. Schaller, of the United States Geological Survey, for the crystal drawings and sketches, prepared largely from material collected by the writer and also from published references.

HALITE (COMMON OR ROCK SALT).

Sodium chloride, or halite (NaCl; sodium (Na) 39.4, chlorine (Cl) 60.6), is a colorless, transparent substance having a brilliance like glass, or, as it is commonly found in nature, white in crystalline or granular form. It occurs crystallized in distinct forms or in compact massive deposits, in places more or less colored by impurities. Its hardness is 2.5 and its specific gravity 2.1 to 2.2. It crystallizes in the anhydrous form in the isometric system, usually in cubes, which commonly unite or intergrow to build up the well-known "hopper forms." In the saline deposits of the desert basin it is also frequently found in octahedral forms. It has perfect cubic cleavage and conchoidal fracture. It is very readily soluble, 100 parts of pure water at 0° C. dissolving 35.59 parts NaCl, and this solubility is but little increased by a rise in temperature, as at 30° C. only 36 parts are dissolved. Halite has a strong saline taste. (See fig. 77.)

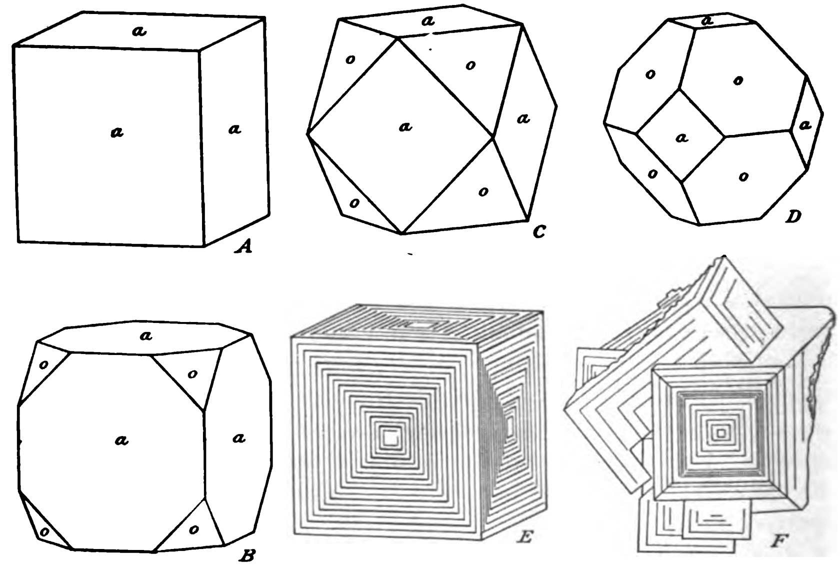

FIGURE 77.—Halite from Searles Lake, Cal., cubic (a) and octahedral (o) forms. Crystal drawings and sketches.

MIRABILITE (GLAUBER SALT).

Decahydrated sodium sulphate, or mirabilite ($Na_2SO_4 . 10H_2O$; sulphur trioxide (SO_3) 24.8, soda (Na_2O) 19.3, water (H_2O) 55.9), is a colorless, transparent crystalline salt, which separates from its solutions by evaporation in the open air or by chilling of its saturated solutions below 33° C., the separation being accompanied by evolution of heat. It forms in large crystals, often needle-like, with the development of many faces in a long, prismatic form. Its hardness is 1.5 to 2 and its specific gravity 1.5. It crystallizes in the monoclinic system. The crystals are readily efflorescent in dry air, losing their water and falling to a white powder. Its common occurrence in nature is therefore in standing saturated solutions or mixed in other salts. It is very soluble in water and its solubility increases markedly with a rise in temperature. At 0° C. 100 parts of water dissolves 5.02 parts Na_2SO_4, while at 33° C., the point of its greatest solubility, the same quantity of water dissolves 50 parts Na_2SO_4. Its taste is cool, then feebly saline, with a bitter aftereffect. (See fig. 78.)

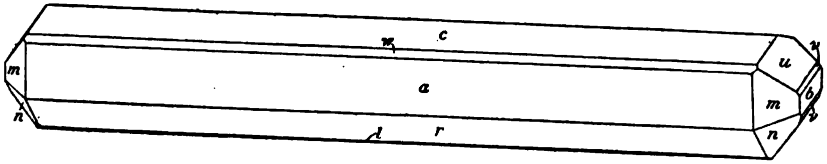

FIGURE 78.—Mirabilite.

THENARDITE.

Anhydrous sodium sulphate, or thenardite (Na_2SO_4; soda (Na_2O) 43.68, sulphur trioxide (SO_3) 56.32), occurs in crystalline form or finely powdered as a result of dehydrating crystallized mirabilite.

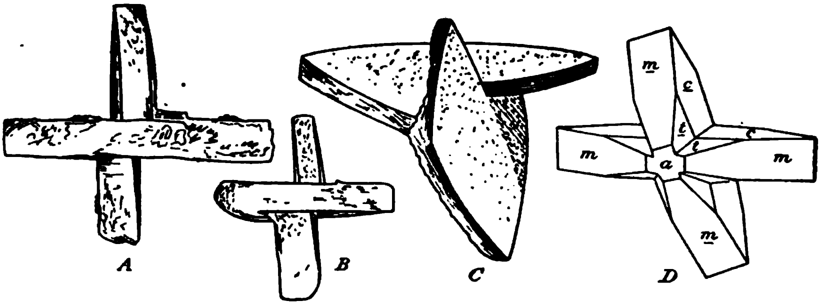

FIGURE 79.—Twinned thenardite. Crystal drawing from Dana; sketches of crystals from Searles Lake, Cal., by W. T. Schaller.

It forms clear transparent to brownish crystals, the color being due to included impurities. It crystallizes in the orthorhombic system in pointed pyramids, combined into crusts, with surface rough. The crystals are commonly twinned, as in some specimens from Searles Lake. (See fig. 79.) In the air it becomes dull by absorbing water. Its specific gravity is 2.655. It results from the evaporation of solutions above 33° C. or from strongly alkaline solutions, as by the addition of sodium carbonate, at ordinary temperatures. It is very soluble in water and has a faintly saline taste.

TRONA (URAO).

Trona, or urao ($Na_2CO_3.NaHCO_3.2H_2O$; sodium carbonate ($NaCO_3$) 46.90, sodium bicarbonate ($NaHCO_3$) 37.17, water (H_2O) 15.93; or in the other form carbon dioxide (CO_2) 38.9, soda (Na_2O) 41.2, water (H_2O) 19.9), is undoubtedly the most important of the natural soda minerals and constitutes the greater part of most natural soda deposits. It occurs as beds of white cavernous material with acicular or bladed crystals lining the cavities, commonly intermixed with more or less earthy material and other salts. It is a glassy or translucent salt, white or stained by impurities. It crystallizes in the monoclinic system, fibrous or columnar massive. It has one perfect cleavage. Its hardness is 2.5 to 3 and its specific gravity about 2.15 in specimens of naturally deposited crystals from Owens Lake examined by Chatard. It appears to be permanent in dry air, is very soluble in water, and effervesces with acids. Its taste is alkaline.

This mineral was shown by Chatard to be among the first of the more soluble constituents to crystallize on concentration of such saline solutions as the waters of Owens and Mono lakes. In the lower part of the main deposit at Searles Lake it occurs as a yellowish caked granular mass, always saturated with the dense mother-liquor brine.

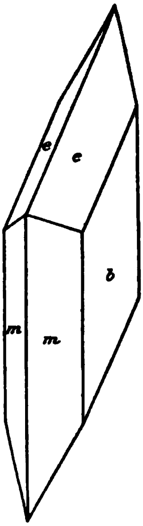

FIGURE 80.—Natron.

NATRON.

Decahydrated sodium carbonate, or natron ($Na_2CO_3.10H_2O$; soda (Na_2O) 21.69, carbon dioxide (CO_2) 15.37, water (H_2O) 62.94), is the ordinary crystal soda of commerce. It forms transparent colorless crystals, as clear as water, of the monoclinic system. (See fig. 80.) It has one good cleavage and another less perfect. According to Thorpe,[1] it crystallizes only at temperatures below 20° C., and thus only under exceptional conditions is it likely to be found in the soda lakes of desert regions, and if formed and exposed it would soon effloresce into the monohydrate ($Na_2CO_3.H_2O$) known as thermonatrite. It liquefies at 34° C.[2] in its water of crystallization, secreting monohydrated salt and leaving a liquid portion containing over 10 molecules of water, and again solidifying when the temperature is reduced to 33½° C. It effloresces quickly in the air and so does not naturally occur in crystal form except as immersed in saturated solutions. Its specific gravity has been variously determined as 1.423 to 1.475. Its taste is strongly alkaline.

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[1] Thorpe, E., A dictionary of applied chemistry, vol. 3, p. 662, 1912.
[2] Lunge, George, Sulphuric acid and alkali, vol. 2, pt. 1, p. 47, 1909.

As stated by Chatard, sodium carbonate is most soluble in pure water at 32.5° C., the solution then containing 59 parts Na_2CO_3 to 100 parts water. Hence a solution which has deposited crystals at the boiling point redissolves them while cooling till the temperature sinks below 32.5° C., when recrystallization begins. The solubility varies greatly with the temperature; thus at 15.5° C. the saturated solution contains 14.53 per cent, at 31.3° C. 30.04 per cent, and at 32° C. 31.78 per cent.

BORAX.

Borax, the sodium tetraborate ($Na_2B_4O_7.10H_2O$; boron trioxide (B_2O_3) 36.6, soda (Na_2O) 16.2, water (H_2O) 47.2), occurs in crystalline form in the Searles Lake deposits, having been extensively worked from the saline crusts in the marshy deposits about the margins of the flat. Borax or some similar compound of boron is also one of the more important constituents of the brine. It has been obtained in drilling as isolated and completely terminated crystals, some of them associated with the crystallized hanksite. It forms in large transparent monoclinic prisms, with truncated lateral edges. The crystals effloresce to an opaque white on the surface when brought into the air but retain their form. Borax crystallizes in the monoclinic system. It has one perfect cleavage and others less distinct, is rather brittle, and has conchoidal fracture. Its hardness is 2 to 2.5 and its specific gravity 1.7. It is soluble in water, especially in hot water, which dissolves double its weight of the salt. It has a sweetish cooling alkaline taste.

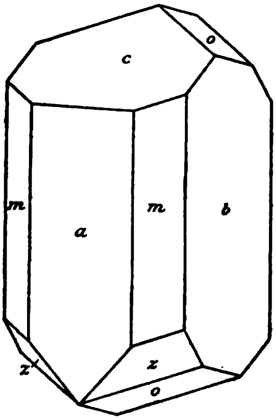

FIGURE 81.—Borax, natural or prismatic form, from Searles Lake, Cal.

Borax forms artificially two varieties of crystals—(1) ordinary or prismatic borax (fig. 81), the decahydrate which is produced by allowing solutions of borax to crystallize by cooling down to the ordinary temperature; (2) octahedral borax, a pentahydrate that separates when a solution crystallizes above 50° C.

GYPSUM.

Gypsum, or hydrous calcium sulphate ($CaSO_4.2H_2O$; sulphur trioxide (SO_3) 46.6, lime (CaO) 32.5, water (H_2O) 20.9), is a common product of desiccation in playa deposits. In its crystalline form (selenite) it is colorless, transparent, often in distinct crystals and aggregates (fig. 82), with very perfect cleavage yielding thin polished folia. Its hardness is 1.5 to 2, and its specific gravity 2.3. It occurs also in fibrous and in massive, fine-grained form, grading into fine earthy deposits mixed with more or less clay (gypsite). It is soluble in hydrochloric acid and 1 part will dissolve in 400 or 500 parts of water. Van't Hoff and Meyerhoffer have shown[1] that the solubility of gypsum gradually increases with rise of temperature from about 0.18 per cent at 0° C. to a maximum of about 0.21 per cent at about 40° C. With further increase in temperature the solubility steadily decreases until at 100° C. it is again 0.18 per cent, or about the same as it was in ice water. The solubility may be increased more than three times by the addition of sodium chloride and more than four times by the addition of magnesium chloride; this increase is explained in part at least by a reaction which produces calcium chloride and at the same time a sulphate of sodium or magnesium.

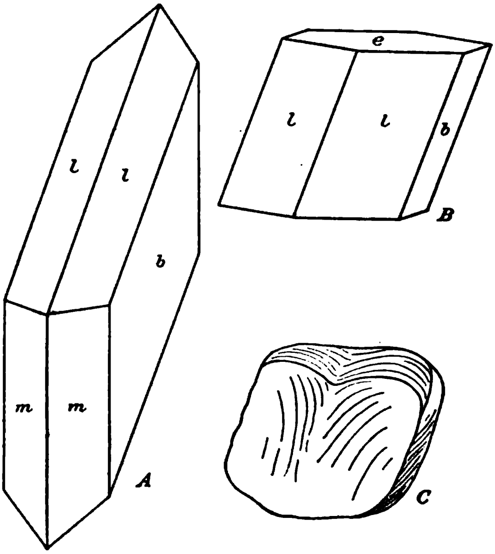

FIGURE 82.—Gypsum (selenite), drawing and sketch from playa-deposited gypsum. The crystal form of *C* is shown by *B*.

In summary the authors cited state that there are but two forms of calcium sulphate which are stable in the presence of any solution—gypsum and natural anhydrite—and the stability of one or the other form depends on the temperature and nature of the solution with which it is in contact. For a calcium sulphate solution the inversion temperature is about 66°, and for a saturated sodium solution it is 30°, the presence of other salts tending to depress the inversion temperature. In pure solution gypsum is stable only up to 66°, when it begins to be transformed into anhydrite, but as the change takes place slowly the solubility may be determined beyond the point of its stability.

ANHYDRITE.

Anhydrous calcium sulphate or anhydrite ($CaSO_4$; sulphur trioxide (SO_3) 58.8, lime (CaO) 41.2) rarely occurs in the form of crystals. It is usually white unless mixed with impurity, massive, cleavable, fibrous, lamellar, granular, and sometimes impalpable. It has three good cleavages in rectangular directions, a property by which it may be distinguished. It is brittle and has an uneven fracture. Its hardness is 3 to 3.5 (harder than gypsum) and its specific gravity 2.9 to 3.0. It is soluble in hydrochloric acid but very slightly soluble in water.

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[1] See summary by Cameron, F. K., and Bell, J. M., Calcium sulphate in aqueous solutions: U. S. Dept. Agr. Bur. Soils Bull. 33, pp. 9 et seq., 1906.

Anhydrite is found generally in deep-seated deposits associated with other salines, but in places where it is protected from the action of moist air. As stated in the section on gypsum, however, it is presumed that anhydrite must have been laid down in such deposits from solutions of rather high concentration of the more soluble salts, as gypsum would ordinarily separate if the solutions were dilute. At or near the surface, in contact with air and moisture, anhydrite is always associated with gypsum, into which it is gradually converted.

GLAUBERITE.

Glauberite ($Na_2SO_4.CaSO_4$; sulphur trioxide (SO_3) 57.6, lime (CaO) 20.1, soda (Na_2O) 22.3) occurs commonly in playa mud deposits in the form of transparent colorless crystals, in thin rhomboids (of plowshare shape) ranging from half an inch to an inch or more in length. It also occurs in more or less massive aggregates of thin rhombic crystals intergrown. (See fig. 83.) It crystallizes in the monoclinic system. It is brittle, with one perfect cleavage, and has a conchoidal fracture. Its hardness is 2.5 to 3; its specific gravity 2.7 to 2.85. It is soluble in hydrochloric acid. In water it loses its transparency and is partly dissolved, the crystal becoming coated with white calcium sulphate. It has a faintly saline taste.

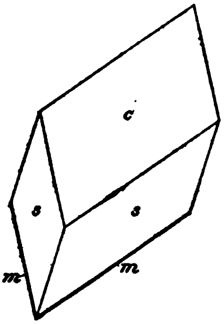

FIGURE 83.—Glauberite from Saline Valley, Cal.

This mineral was described by Blake[1] as occurring in Verde Valley, Ariz., embedded in compact green clay in crystal form evidently resembling that observed in other saline playa deposits. Good specimens of the crystallized mineral were found embedded in the clays underneath the surface-salt crust in Saline Valley, Cal.,[2] and both large and small distinct idiomorphic crystals have been found in the drill samples obtained at various depths down to 100 feet in the Geological Survey boring in Death Valley, Cal., where the crystals were likewise embedded in moist, heavily saline muds.

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[1] Blake, W. P., Am. Jour. Sci., 3d ser., vol. 39, p. 14, 1890.

[2] Acknowledgment is due to Mr. Earl Patterson, of Bishop, Cal., for specimens of glauberite from Saline Valley.

HANKSITE.[1]

Hanksite ($9Na_2SO_4.2Na_2CO_3.KCl$; sodium sulphate (Na_2SO_4) 81.7, sodium carbonate (Na_2CO_3) 13.5, potassium chloride (KCl) 4.8) was first identified in 1885 by W. E. Hidden in collections from Searles Lake, where it is found in large amounts, chiefly in isolated crystals, commonly of quartzoid form, although found also in flattened tabloids. (See fig. 84.)

The mineral is clear, transparent, and almost colorless, inclining to a more or less decided yellow, but often clouded by impurity. It crystallizes in the hexagonal system. It has one distinct cleavage and is brittle, with uneven fracture. Its hardness is 3 to 3.5; its specific gravity, 2.55. It is readily soluble in water, effervesces with acid, and has a strongly alkaline taste.

Hanksite was originally found embedded in the soft muds about the margin of the marsh and was noted in the records of the deep well from depths of 2 to 6 feet, 14 to 22 feet, and 50 to 70 feet. Subsequent drilling in the main salt deposit has developed a zone or layer of hanksite probably extending throughout the deposit at depths of 25 to 30 or 35 feet. This bed varies considerably but is very commonly 5 feet or more in thickness and seems to be composed chiefly of beautifully distinct double-ended hexagonal prisms and pyramids, which much resemble quartz crystals in form. They range in size from minute grains of perfectly developed form to crystals several inches in length.

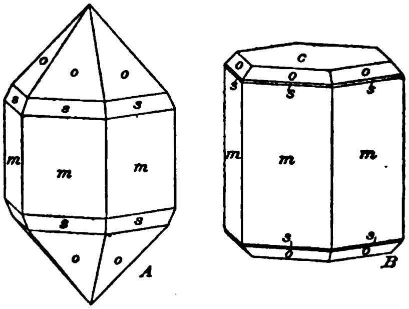

FIGURE 84.—Hanksite from Searles Lake, Cal.

NORTHUPITE.[2]

Northupite ($MgCO_3.Na_2CO_3.NaCl$; magnesium carbonate ($MgCO_3$) 33.9, sodium carbonate (Na_2CO_3) 42.6, sodium chloride ($NaCl$) 23.5) has been found only among materials brought from the deep well at Searles Lake, where it was reported as occurring in a stratum of clay encountered at a depth of about 450 feet. It is colorless, transparent or glassy when pure, but often clouded by impurities. It apparently suffers no decomposition on exposure to the air. Except for two crystals attached to pirssonite, northupite has been observed only in detached crystals. It crystallizes in the isometric system, the octahedron being the only form observed. (See fig. 85.)

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[1] Hidden, W. E., Am. Jour. Sci., 3d ser., vol. 30, p. 133, 1885. Dana, E. S., and Penfield, S. L., idem, p. 136. Hanks, H. G., idem, vol. 37, p. 63, 1889. De Groot, H., California State Min. Bur. Tenth Ann. Rept., p. 534, 1890. Pratt, J. H., Am. Jour. Sci., 4th ser., vol. 2, p. 133, 1896.

[2] Foote, W. M., Acad. Nat. Sci. Philadelphia Proc., Sept., 1895; Am. Jour. Sci., 3d ser., vol. 50, p. 480, 1895. Pratt, J. H., Am. Jour. Sci., 4th ser., vol. 2, p. 123, 1896.

The crystals are small, being from less than a millimeter to nearly a centimeter in diameter. There is no apparent cleavage. The crystals are extremely brittle and show conchoidal fracture. Its hardness is 3.5 to 4; its specific gravity, 2.38. It is very slightly soluble in cold water, although rapidly decomposed by hot water, with separation of magnesium carbonate, and it is easily soluble and effervesces in dilute hydrochloric acid.

This mineral was discovered by C. H. Northup in material from the deep well at Searles Lake, which is described on another page. Small crystals were obtained by painstaking search of the "tailings" or débris thrown out from the boring.

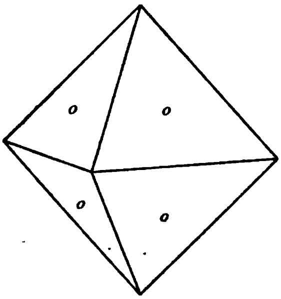

FIGURE 85.—Northupite from Searles Lake, Cal.

PIRSSONITE.[1]

Pirssonite ($CaCO_3.Na_2CO_3.2H_2O$; calcium carbonate ($CaCO_3$) 41.3, sodium carbonate (Na_2CO_3) 43.8, water (H_2O) 14.9) was first recognized among some crystals of gaylussite found in the deep well at Searles Lake, and has been reported only from that locality. With the exception of two crystals which were attached to northupite crystals, pirssonite was at first observed only in detached crystals. It has, however, been found among the well samples in fragmental form, presumably having been pounded up by the drill, and also in a massive aggregate acting as a sort of cement in more or less consolidated muddy layers of the deposit. The mineral crystallizes colorless, transparent or darkened by impurities, in the orthorhombic system and is hemimorphic in its development. (See fig. 86.) It is extremely brittle, having conchoidal fracture with no apparent cleavage. Its hardness is 3 to 3.5 and its specific gravity 2.35.

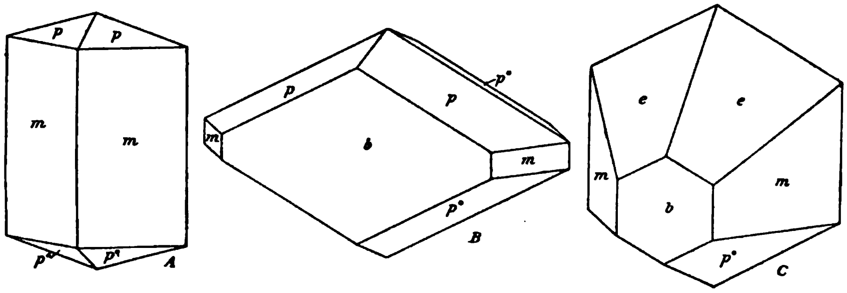

FIGURE 86.—Pirssonite from Searles Lake, Cal.

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[1] Pratt, J. H., Am. Jour. Sci., 4th ser., vol. 2, p. 126, 1896.

GAYLUSSITE.[1]

Gaylussite, a hydrous carbonate of calcium and sodium ($CaCO_3.Na_2CO_3.5H_2O$; calcium carbonate ($CaCO_3$) 33.8, sodium carbonate (Na_2CO_3) 35.8, water (H_2O) 30.4), is a colorless transparent mineral occurring in small glassy crystals, many clouded by impurities, usually found embedded in mud or clay. It crystallizes in the monoclinic system. (See fig. 87.) It has one perfect cleavage and a conchoidal fracture. Its hardness is 2 to 3; its specific gravity 1.9 to 1.95. It is slightly soluble in water, the sodium carbonate going into solution and leaving a white coating of calcium carbonate on the crystal surface. It effervesces briskly with acids.

Gaylussite was first reported from Searles Lake by Hanks,[2] but it appears[3] that there must have been some mistake in his identification, for, as pointed out by Pirsson, the reactions which he ascribed to the mineral are impossible for gaylussite. All the authentic specimens of gaylussite from Searles Lake have been distinct crystals, with sharp idiomorphic outline.

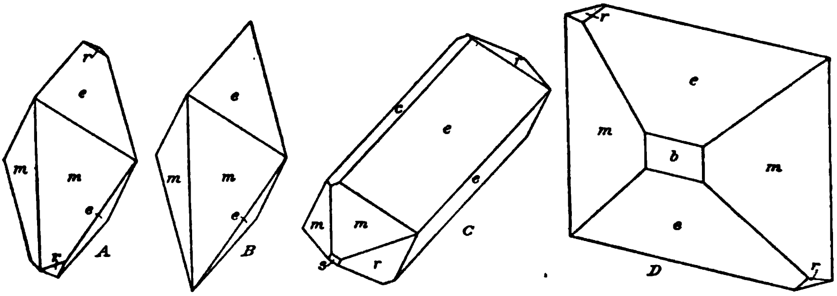

FIGURE 87.—Gaylussite.

Although gaylussite may be of common occurrence in desert playa and dry-lake deposits generally, it has not until recently been very frequently noted. It is described as occurring at the Soda Lakes near Ragtown, Nev., in the reports by Silliman and Blake cited above. Prospecting in Railroad Valley, Nev., has revealed its presence as a layer in the surface playa muds over an area of 7 or 8 square miles, where an average of some 25 per cent in a thickness of about 1 foot is said to consist of gaylussite in distinct crystal grains.[4] In addition large buried deposits of this mineral at depths below 700 feet have been revealed by drilling, most of the mineral recovered having the distinct and individual isolated crystal form. It has also been found under similar conditions at other places, as in Dixie Valley and Columbus Marsh, Nev. The accompanying figures show forms obtained from the borings in Railroad Valley, representing each of the crystals figured by Pratt as obtained from the deep well at Searles Lake.

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[1] Boussingault, M., Annales chim. et phys., vol. 31, p. 270, March, 1826. Phillips, W., Philos. Mag., vol. 1, p. 263, London, April, 1827. Des Cloizeaux, A., Annales chim. et phys., 3d ser., vol. 7, p. 489, 1843. Des Cloizeaux, A., Annales des mines, 5th ser., vol. 14, p. 400, 1858. Fritzsche, J., Jour. prakt. chemie, vol. 93, p. 339, 1864. Silliman, B., Am. Jour. Sci., 2d ser., vol. 42, p. 220, 1866. Blake, W. P., idem, p. 221. Des Cloizeaux, A., Manuel de minéralogie, vol. 2, p. 171, 1874. Arzruni, A., Zeitschr. Kryst. Min., vol. 6, p. 24, 1882. Rammelsberg, C. F., Jour. prakt. Chemie, vol. 35, p. 106, 1887. Pratt, J. H., Am. Jour. Sci., 4th ser., vol. 2, p. 130, 1896.

[2] Hanks, H. G., Gaylussite, on a new variety from San Bernardino County, Cal.: Min. and Sci. Press, vol. 64, p. 222, Mar. 26, 1892.

[3] Pratt, J. H., loc. cit.

[4] Report of the Railroad Valley Co.

SULPHOHALITE.[1]

Sulphohalite, a sodium sulphate, chloride, and fluoride ($2Na_2SO_4.NaCl.NaF$; sodium sulphate (Na_2SO_4) 73.9, sodium chloride ($NaCl$) 15.2, sodium fluoride (NaF) 10.9), a transparent mineral with faint greenish-yellow color, occurs in distinct crystals in association with hanksite at Searles Lake. Besides the two mentioned below, only four specimens of this mineral are known, and all are from the same locality. They were found in the Searles deep well at a depth of 35 feet, where they were associated with a considerable quantity of hanksite. The crystals are isometric, simple rhombic dodecahedrons and octahedrons in form, with a tendency to hemihedrism where the two forms are combined, the octahedral faces being present only on the alternate trihedral solid angles of the dodecahedrons, and of distinct shape, with sharp angles and smooth-polished crystal faces. (See fig. 88.) The crystals vary in size from 0.5 centimeters to 2.5 centimeters in diameter. The specific gravity is 2.5 and the hardness about 3.5. The mineral is very slowly soluble in water and remains unaltered in a moderately dry atmosphere. The occurrence of fluorine is notable in the series of saline minerals deposited from concentrated lake waters, fluorine, like borax, being generally considered an index of fumarole or solfataric action.

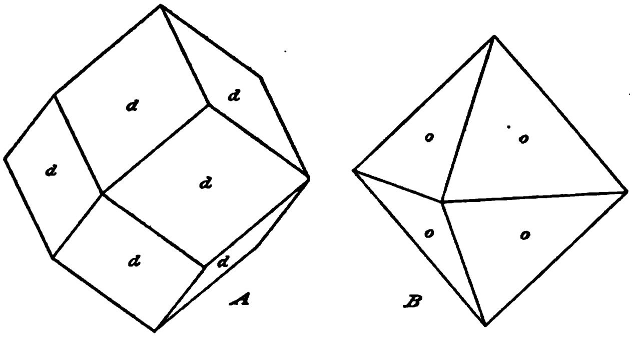

FIGURE 88.—Sulphohalite from Searles Lake, Cal.

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[1] Mackintosh, J. B., Am. Jour. Sci., 3d ser., vol. 36, p. 463, 1888. Hidden, W. E., idem, vol. 41, p. 438, 1891. Twelvetrees, W. H., idem, 4th ser., vol. 6, p. 511, 1898. Penfield, S. L., idem, vol. 9, p. 425, 1900. Gale, H. S., and Hicks, W. B., idem, vol. 38, p. 273, 1914.

Originally only rhombic dodecahedrons were described for this mineral, but lately two almost perfect octahedrons noted by the writer among some hanksite crystals in a collection belonging to Dr. S. P. Sadtler, of Philadelphia, were subjected to analysis and proved to be sulphohalite.

TYCHITE.[1]

Tychite ($2 MgCO_3.2Na_2CO_3.Na_2SO_4$; magnesium carbonate ($MgCO_3$) 32.3, sodium carbonate (Na_2CO_3) 40.5, sodium sulphate (Na_2SO_4) 27.2) was discovered by the merest chance in 1895, when some northupite crystals from Searles Lake were being studied in the mineralogic laboratory of the Sheffield Scientific School at New Haven, Conn. A single very small specimen, which happened to be the first of a lot selected from among a large number of octahedral crystals for chemical test, was found to differ in composition from what had been expected and was thereupon identified as an entirely new species. Out of fully 5,000 specimens examined the very first crystal and one of the last ten crystals tested proved to be the new mineral and only two other specimens were found. All but the last were lost in an unsuccessful attempt to make an analysis. The last was a very small octahedron weighing but 0.0109 gram. No other natural crystals have ever been found.

The individual crystals are transparent and colorless, effervesce readily with acid, and were distinguished from northupite by the fact that they gave no chloride test but a sulphate reaction instead. The composition was later determined from similar material prepared synthetically, which is supposed, however, to be the true mineral. Its specific gravity is about 2.45; its hardness about 3.5 to 4. It is almost insoluble, even in hot water. It crystallizes in the isometric system in octahedrons.

SEARLESITE.[2]

Searlesite, a hydrous sodium borosilicate ($Na_2O.B_2O_3.4SiO_2.2H_2O$), in spherulites of radiating fibers, was found embedded in the muds in the Searles deep well at a depth of 540 feet. It is colorless or white. It is soft and its gravity has not been determined on account of lack of material. It is intimately associated with calcite and less intimately with pirssonite. It may prove of particular interest if found more abundant, as it contains theoretically about 17.15 per cent of boric acid.

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[1] Penfield, S. L., and Jamieson, G. S., Am. Jour. Sci., 4th ser., vol. 20, p. 217, 1905.

[2] Larsen, E. S., and Hicks, W. B., idem, vol. 38, p. 437, 1914.

HISTORY OF THE SEARLES LAKE DEPOSITS.

According to De Groot [1]—

> This extensive and valuable deposit of borax was discovered by John W. Searles, who first observed signs of this salt when crossing the marsh that now bears his name, in 1862, at which time he was engaged in prospecting for gold in the Slate Range, lying to the east. Being unacquainted with the nature of the substance, he did not at the time pay much attention to it. Afterward, however, when borax began to be an object of general inquiry, he recognized in some samples of this salt shown him the stuff he had noticed while crossing this alkaline flat several years before. Satisfied on this point, he at once took proper steps for locating such portions of the marsh as he considered most valuable.

The deposit is reported to have been located by J. W. Searles and E. M. Skillings on February 14, 1873. Borax was then obtained from the surface scrapings over the mud deposits about the margin of the main salt area, operations which have already been referred to.

Probably the first to suggest that potash might become one of the profitable products of this deposit was Whitman Symmes, who in 1898 was superintendent of the California Borax Co., operating at Searles Lake. Mr. Symmes is said to have at that time located nearly the whole of the salt area of this deposit with the object of working the brine for the extraction of its borax, soda, and potash. The enterprise did not find sufficient support and was allowed to lapse.

In 1908 the whole deposit (41,200 acres, or about 65 square miles) was again located and subsequently was relocated by C. E. Dolbear and seven others for the purpose of establishing there a carbonate of soda or "soda ash" industry. An extensive plant was put in, but for one reason or another the whole equipment was allowed to become idle before any of the soda was shipped.

The announcement of Searles Lake as a possible source of potash, which directed public attention throughout the country to the deposit, was made in a joint press bulletin issued by the United States Geological Survey and the Bureau of Soils soon after the first telegraphic press reports late in March, 1912. This announcement is quoted in full as follows:

POTASH IN "BORAX LAKE"—ANCIENT LAKE BED IN MOHAVE DESERT OF SOUTHERN CALIFORNIA MAY FURNISH MILLIONS OF TONS.

> The two Federal bureaus engaged in the search for potash—the Bureau of Soils of the Department of Agriculture and the Geological Survey of the Department of the Interior—are in receipt of promising telegraphic news from their field representatives. A potash deposit of apparently great importance has been discovered at Borax or Searles Lake, in the northwestern corner of San Bernardino County, Cal. This lake or playa is the last remaining pocket of a once much greater lake which has almost dried up, and its central depression contains a large body of crystalline salts known to consist of common salt and sulphate and carbonate of soda with smaller quantities of borax. This salt body is saturated with brine, and interested persons stimulated by the

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[1] De Groot, H., The Searles borax marsh, California: California State Min. Bur. Tenth Ann. Rept., pp. 534–539, 1890.

governmental search for potash recently secured an analysis of old sample material from this brine. The result being significant, the lake was visited jointly by representatives of the Geological Survey and of the Bureau of Soils, who took brine samples from six wells distributed over the salt flat. Analyses of these samples have been made by the cooperative laboratory at the Mackay School of Mines, at Reno, Nev., and show an average of 6.78 per cent of potassium oxide (K_2O) in solution. The average salinity of the brine is 43.82 grams of solids per 100 cubic centimeters. Comparison of the results indicates that the brines are nearly uniform throughout the flat. The probable importance of the deposit is due to the occurrence of the potassium salts in soluble form in a natural saturated brine and under climatic and other conditions especially favorable to its separation and recovery by solar evaporation. Existing data give reasonable assurance that the brine-saturated salt body is at least 60 feet thick and covers an area of at least 11 square miles. Assuming the salt body to contain 25 per cent by volume of the brine, the total amount of potassium oxide is estimated at over 4,000,000 short tons. This estimate is believed to be very conservative and the available tonnage may well be expected to exceed 10,000,000 tons, which would supply the country, at the present rate of consumption of potash, for 30 years. At any rate it appears that this locality constitutes a very important source of potash in probably readily available commercial form.

Methods of separating potash from brines are now under investigation by the Bureau of Soils.

This statement was based on the evidence from analyses of a representative set of brine samples collected jointly from the main deposit early in March by E. E. Free, then of the Bureau of Soils, and the writer. Shortly before the making of this announcement a report had been received that an attempt to exploit the deposit as a source of potash was being made on the basis of three analyses that had been made for this purpose not long before by a firm of private chemists. The materials from which these analyses were made were some sample residues that had been kept from a previous investigation of this deposit with special reference to soda and borax. The three analyses were in effect an afterthought, being made in response to a suggestion concerning a possible potash value in the deposit, which came after the original work on the samples had been completed. Only one of these analyses (the one quoted on p. 311) showed an apparently significant amount of potash. One analysis of this set has already been quoted (p. 294); the other two are as follows:

Early analyses to show potash content of Searles deposits.

Salts.	
Insoluble in water	1.44
Sodium chloride (NaCl)	45.90
Sodium sulphate (Na_2SO_4)	22.80
Sodium carbonate, anhydrous (Na_2CO_3)	16.57
Sodium bicarbonate ($NaHCO_3$)	6.50
Sodium biborate, anhydrous ($Na_2B_4O_7$)	2.32
Potassium chloride (KCl)	3.64
	99.17

Brines.

[Specific gravity, 1.300 at 23° C.]

	Grams per 1,000 cubic centimeters.	Per cent in original sample.
Insoluble in water	262	20.15
Sodium sulphate, anhydrous (Na_2SO_4)	71	5.46
Sodium carbonate, anhydrous (Na_2CO_3)	60	4.62
Sodium bicarbonate	Trace.	.00
Sodium biborate, anhydrous ($Na_2B_4O_7$)	17.2	1.32
Potassium chloride	(1)	4.50
		36.05

The analysis of the salts was made on a composite sample, an average of the salts obtained from borings in the deposit, but exclusive of material from the uppermost 20 feet. The brine analysis was made on a similar composite of all samples of the well waters then on hand. These analyses are only partial, as that of the brine fails to report the sodium chloride, which is the principal constituent, but the potassium reported corresponds approximately with the results that have subsequently been obtained on other samples. The analyses are quoted here mainly for their historical interest.

Although undue emphasis should not be placed on the fact that the Government agents who examined the deposit thus issued the first public announcement of the deposit as a likely source of commercial potash, nevertheless it is only proper to make clear the circumstances under which these events took place. Only a very few potash analyses from this deposit, made by private persons, showing in any way a potash content in the brines or salts of this deposit were at that time extant. Some apparently extravagant statements had previously been issued, based on what was deemed by many to be insufficient information, the results of a single analysis. In view of this skepticism the Government tests were made and the single potash determination of one of the first of the private tests referred to was substantially confirmed. The announcement quoted above was the first favorable opinion as to any desert-basin saline deposit that had yet been examined in the course of the general field investigation by the Government. This favorable opinion was based mainly on the fact that this basin seemed to fulfill almost entirely the conditions of the hypothesis for the formation of the desert-basin salines on which the field explorations by the Geological Survey had been based.

PROSPECTIVE COMMERCIAL DEVELOPMENT.

The prospective development of the Searles Lake deposits is naturally a matter of considerable interest as an enterprise without precedent in this country. According to late advices [2] construction on the new

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[1] Quoted as 36.9 grams K_2O in 1,000 cubic centimeters original solution, or 5.84 per cent KCl.

[2] Eng. and Min. Jour., vol. 97, No. 9, p. 484, Feb. 28, 1914.

experimental unit in which the American Trona Corporation will begin the manufacture of potassium chloride and other salts from the brine of Searles Lake is progressing. The 31-mile railroad from Searles, on the Southern Pacific Railroad, to the new town of Trona, where the works are being built, is nearly completed. The preliminary plant, it is reported, will handle 20,000 gallons of brine daily, and when the process and equipment have been thoroughly proved by actual operation the works will be enlarged. The salts from the Searles Lake deposit, it is stated, probably will not enter the market regularly until late in 1914. In the meantime a very large number of borings have been sunk through the deposit. This work is intended to serve the purposes of assessment or patent requirements on the claims and to prove the extent and nature of the deposits in depth and areally.

Such an undertaking is primarily a chemical manufacturing enterprise, whose success will depend on the utilization of all advantages or economies to be gained by large-scale production and the use or sale of all possible by-products, as well as on the skill developed in handling the physical and chemical problems involved in the separation of the salts. The commodities to be produced are already being supplied in the market, and it is expected that competition for a place in the industry will be keen. The products are bulky and relatively low priced, so that they will suffer the disadvantages of heavy transportation charges in order to reach many of the important markets of the country. Moreover, the initial investment for such an operation is necessarily heavy.

PANAMINT VALLEY.

THE FORMER LAKE.

While the waters in the Searles Basin stood at their highest level they undoubtedly overflowed by way of the pass at the south end of that basin and entered the larger and deeper basin of the Panamint Valley. Here they formed the principal water supply of a lake which of course received also contributions of the desert drainage tributary to its valley. This immense body of water, having an origin similar to that of Searles Lake, may have produced in the Panamint Valley saline deposits resembling those in the Searles Basin, but there are many qualifying factors to be considered in offering judgment as to whether this is or is not the case.

Panamint Lake was 60 miles in length from north to south and 5 or 6 miles wide for the greater part of its length, though nearly 10 miles wide in the broader portion of the valley north of Ballarat. It was of a different form from the lake in the Searles Basin, being confined in a long, relatively narrow and deep basin, whereas Searles Lake occupied a broad oval basin. Panamint Lake narrowed to a point at its south end, and this was not only the point of inlet for the overflow from the Searles Basin but it appears that the inlet was also near the position of its probable outlet or overflow during the period of its maximum flooding. The greatest depth of Panamint Lake was probably determined by Wingate Pass, through which an overflow is believed to have passed for some time into Death Valley. The feature of this outlet was not at first recognized but has been brought to attention with the completion of topographic mapping about the south end of the Panamint Basin. It is also a feature that deserves further study on the ground, as it offers a possibility of developing even more of the historical record of this drainage system, which certainly has not before been fully interpreted. The area of Panamint Lake at its various water levels is indicated by the following planimeter measurements obtained from the topographic map:

Area of former Panamint Lake at different levels.

Elevation of water level.	Area.
Feet.	*Square miles.*
1,977	272.55
1,900	252.20
1,800	221.48
1,700	189.88
1,600	141.32
1,500	129.02
1,400	110.03
1,300	93.21
1,200	74.89
1,100	54.10
1,045	19.32

At its uppermost recorded elevation the water stood 930 feet above the present valley bottom opposite Ballarat. The original lake was doubtless considerably deeper, the basin having been subsequently filled by inwashed sediment, but as yet little can be said as to the depth of this filling.

Calculations of the volume of the ancient lake at its various levels are given in the following table. These are based on application of the prismoidal formula to horizontal sections of the present basin, as was done in the computations on the Searles Basin.

Calculated volume of former Panamint Lake basin.

Inclusive contours.	Depth of section.	Volume.
Feet.	*Feet.*	*Acre-feet.*
1,977-1,900	77	12,927,000
1,900-1,800	100	15,147,000
1,800-1,700	100	13,151,000
1,700-1,600	100	10,560,000
1,600-1,500	100	8,648,000
1,500-1,400	100	7,642,000
1,400-1,300	100	6,496,000
1,300-1,200	100	5,369,000
1,200-1,100	100	4,110,000
1,100-1,045	55	1,241,000
		85,291,000

Evaporation during the maximum flood stage, as well as inflow and evaporation within the basin during receding stages of the lake waters, when the lake could have had no outlet, may have greatly increased the total volume of waters that were eventually evaporated within the basin. Panamint Lake is apparently analogous to Searles Lake, as each lake received its waters by overflow from a higher basin and each at some stage undoubtedly overflowed to a lower basin.

The evidence at hand concerning the existence of the ancient lake in the Panamint Basin is briefly as follows:

East or southeast of the old town of Ballarat on both sides of the mouth of Pleasant Canyon is an immense bowlder delta of material evidently derived as wash from the adjacent mountain slopes and carried out by way of the drainage channels. This delta is flat-topped and abruptly truncated on the valley side, a peculiar relation which first attracted attention to it as a probable delta deposit formed under standing water. The normal alluvial deposit formed under subaerial conditions is of course a graded slope extending for a greater or less distance into the valley. The abrupt truncation of such deposits might be explained by differential offsets due to recent fault movement, but the idea that first presented itself was that this coarse alluvial material was thrown down by torrential floodwaters when they were checked by meeting the standing water. This idea appealed to Campbell,[1] who probably was the first to record the existence of a late Quaternary lake in this basin. Campbell described the immense bowlder deltas at the mouth of Wild Rose Canyon and above Ballarat as evidently deposited in a body of standing water. Judging from the slope of the bowlder surfaces, he expressed the conclusion that there had been rather profound warping or faulting in the region since the lake period. This may be true concerning a preceding glacial-lake history (see p. 320) not yet definitely established, but as regards the present most evident succession of old lake-shore benches the determinations of elevation from point to point about the basin have not yet shown any great amount of displacement.

The gravel ridges back of Ballarat have none of the internal structure of typical deltas. When flowing water enters a body of standing water its load of coarse material is normally carried forward with the current until the water loses its motion by mingling with the deeper waters, when the suspended load sinks, being deposited in layers with marked inclination toward the deeper parts of the basin. As the delta is built out the surface is extended with a thinner section of relatively horizontal layers, but the advance at the front consists of the deposition of inclined beds, in a way analogous to the building out of a mine dump where the waste is carried forward in mine cars and emptied over the edge, while a certain portion is spilled along the top. The ridges back of Ballarat show none of these "foreset" features and consequently suggest that they may be portions of the prelacustral valley fill, elevated to their present positions by faulting. There is some other evidence to support this hypothesis. It may be, therefore, that these bars, which were at first taken as evidence of the existence of an ancient lake in this basin, have no direct relation to the lake history of the valley.

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[1] Campbell, M. R., Reconnaissance of the borax deposits of Death Valley and Mohave Desert: U. S. Geol. Survey Bull. 200, p. 20, 1902.

However, the evidence of ancient shore markings, including the usual wave-cut terraces, tufa deposits, and characteristic light-greenish saline clays in thin-bedded deposits at certain places about the shores, gives indisputable evidence that such a lake existed and indicates about what its maximum depth must have been.

Some rather unsatisfactory barometer readings for elevation on the slope east of Ballarat up to the level of the upper shore terraces seemed to indicate that the old lake had stood 1,200 or 1,300 feet above the valley. There is some doubt as to the value of this determination, in the face of later evidence. Duplicate barometer readings showed with practical agreement an elevation of 1,950 feet for the lower of two distinct shore benches near the Ballarat-Searles road southwest of Ballarat. An upper bench 20 or 30 feet higher than this is the highest of these terraces recognizable in this part of the valley. One barometer reading on the shore lines east of Ballarat agrees with this determination. On another trip along the whole length of the Panamint Valley to the extreme south end barometer readings with frequent checks on standard bench-mark elevations gave additional evidence. In the southern part of the valley the shore lines are not everywhere easy to recognize. Moreover, a number of the original metal bench-mark posts set in that part of the country had been erroneously marked with an elevation just 100 feet in excess of the actual elevation determined, and this upset the field calculations. The figures given on the Survey topographic map (Searles Lake sheet), however, are the corrected ones. Near Wingate Pass, at an elevation of 1,900 to 1,910 feet in the main Panamint Valley (checked on bench mark 1916 at the forks of the road to Lone Willow) there are thin-bedded horizontal greenish-white marl-like clays, covered in exposure with a white saline efflorescence such as is very characteristic of water-deposited sediment along the tributary inlets of desert lakes elsewhere. If these beds were deposited under water the highest lake level should be looked for still higher (above 1,916 feet). No actual shore traces were observed just here, although doubtless favorable conditions of light might serve to bring them out, but terraces and benches of the same light-greenish clays appear from this point to the north (down the valley) for a considerable distance. The bedding of these deposits shows a slight inclination toward or down the valley. They are believed to be only remnants of much more extensive deposits which have been worn away by erosion. A few miles farther down the valley, about opposite Wingate Pass, the marly clay "lake beds" are conspicuous and contain scattered crystals of selenite. Distinct horizontal shore lines were noted in the slope below Wingate Pass and are assumed to represent stages of greater or less permanence of water level during the recession of the ancient lake. From this point northward down the valley faint but undoubted shore markings of the higher levels show from place to place, peculiar or favorable light serving to bring them out at times with great distinctness. Thus, the lowering sun often casts a shadow over a succession of benches on the west side of the valley, bringing them out with much distinctness. Shore lines were observed above the Redlands mill, on the east side of the valley 9 or 10 miles south of Ballarat, and at various other places. On coming into the town of Ballarat from a northwesterly direction in late evening light, one sees from the center of the mud flat a series of shore-line markings high on the mountain slopes of the east side of the valley, and these extend for a long distance, appearing plainest on the smooth slopes north and south of Pleasant Canyon. These markings are preserved especially well on the steeper slopes of wash débris, such as the wash deposits near the mouths of the deeper gulches, but are generally unrecognizable along the greater part of the more rocky slopes about the valley.

The final bit of evidence concerning the maximum water level of the Panamint Lake was found in the contouring and elevations in Wingate Pass, which leads from the Panamint Valley into Death Valley. These data were obtained in recent surveys for maps now in preparation. Wingate Pass has an elevation of 1,977 feet above sea level (the bench-mark post at the summit 10 feet east of the road, 2½ miles east of the junction of the road in Panamint Valley, standing at 1,976.778 feet). This pass, which is the only possible point of outlet for such a lake, has not yet been visited for the purpose of determining what evidence it may afford as to an overflow into Death Valley, but the coincidence of this elevation with the elevations of upper shore traces in other and distant parts of the valley seems to indicate not only that such an outlet existed for a time at least, but also that subsequent faulting, warping, or tilting in the valley may not have greatly modified the Panamint Lake basin, as was suggested by Campbell.

The various shore levels on the valley margin slopes are more or less conspicuously marked by lake-deposited tufa, a calcareous coating apparently similar to the corresponding deposits in the Lahontan and Bonneville basins described in detail by Gilbert[1] and Russell.[2] The latest deposit of this material appears as a low reef 8 or 10 feet above the mud flat, especially along the west shore opposite Ballarat. This reef is assumed to have been formed by the deposition of lime from solution in lateral seepage waters which may have entered during a period of shallow submergence of the mud flat to the depth indicated. Much scattered tufa was observed at an elevation of about 1,220 feet (barometric) and at other levels, the highest being at about 1,970 to 1,980 feet, which is, as noted above, the elevation of the probable outlet.

Some clue as to the age of Panamint Lake may be indicated in a collection of fossils obtained from the tufa of the lake-shore deposits at the 1,950-foot level along the Searles-Ballarat road. These were submitted to W. H. Dall, who reports as follows:

> I have examined the fossils from the Lahontan Basin and Panamint Valley, referred to in the letter of Hoyt S. Gale dated December 9, 1913. They belong to the characteristic Quaternary fauna of the Great Basin and are of probably the same geologic age. Those from the Panamint Valley comprise the following species:
>
> Carinifex newberryi Lea.
> Pompholyx costata Hemphill.
> Lymnæa utahensis Call.
> Physa humerosa Gould.
> Valvata utahensis Call.
> Amnicola dalli Call.
> Amnicola cincinnatiensis (Anth.) Call.

GEOLOGIC STRUCTURE OF THE PANAMINT VALLEY.

The structure suggested by the Panamint Valley is that of a down-faulted block or "graben" in which the greatest depression appears to have been on the east side of the valley, as is indicated by the present profile of the valley cross section, the abrupt rock wall of the east contrasting with the broad alluvial slopes reaching into the valley from the west. The hot spring at the north end of the valley and the springs near Ballarat indicate a zone of faulting along this edge of the valley, and the abrupt truncation of the delta deposits near Ballarat may be in part due to faulting before the period of lake occupancy. This might account for the position of the lowest valley depression near the eastern valley margin, and a similar position is suggested for a possible concentration sink in the desiccation of former lake waters. If the topography of Panamint Valley has been greatly modified since the recession of that ancient lake, it seems as if the modification must have been effected by faulting along this line or by the extravasation of alluvial material from the rocky canyons and precipitous slopes of the eastern valley margin. From present appearances it is hard to see how either process has accomplished any specially significant changes.

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[1] Gilbert, G. K., Lake Bonneville, U. S. Geol. Survey Mon. 1, 1890.

[2] Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U. S. Geol. Survey Mon. 11, 1885.

The Warm Springs, at the north end of the mud flats 5 miles north of Ballarat, seem to occupy a local sink in which a small distinct drainage leads toward the springs through minor channels in the playa. This apparent anomaly may be accounted for either wholly or in part by recent fault drop tilting down this edge of the basin, while it is also true that this corner, protected by lying at the very foot of a precipitous rock wall, receives inwash only along the valley from either the north or the south side of this steeper slope and so forms a natural basin in the slope of valley sediments. The crusted salts about this basin have been scraped for local domestic and stock use. A pond of exceedingly briny water occupies the bottom of the depression below the springs.

DRILLING IN PANAMINT VALLEY.

Prospecting in the Panamint Valley for buried saline deposits was begun by private interests in November or December, 1913. One or more shallow holes had been sunk earlier in the year, it is supposed with inconclusive results. The more complete exploration of this basin offers a practical test of the hypothesis of buried salts as a result of the desiccation of a Quaternary lake that is known to have evaporated and left only an insignificant deposit on the surface. The possibilities seem to be various, and the result of a complete test is to be watched for with interest.

A saline deposit, if one exists in the Panamint Valley, will doubtless be of much the same type as that of Searles Lake, for it must have been formed chiefly by overflow of the waters that passed through the Searles Basin. As the waters of Searles Lake were supposedly dilute during their higher stages it seems unlikely that much differentiation could have taken place within them, and the overflow to the Panamint Lake was not in the nature of a mother liquor.

In speculation concerning a possible saline deposit in the Panamint Valley two prime questions present themselves, which probably can be answered only by the use of the drill. First, did concentration below the level of overflow go on in this basin for a sufficiently long time for a great mass of salines to have accumulated as in the Searles Basin? Second, if the concentration took place and the salts were deposited on the evaporation of the lake, has the valley been filled to such an extent that the deposits are inaccessible? The only judgment that can be offered in these matters, until they are tested by drilling, is that to be had from the study and interpretation of the records left by the lake waters, such as the evident permanence of former lake levels, the size and importance of inflow and overflow channels, and the amount of modification the basin has undergone since it was occupied by water. These records may indicate probabilities, but as yet they do not seem to be conclusive.

Some quantitative idea of the interpretations to be placed on this lake history may be obtained from the following computations: The water content of the ancient Panamint Lake at its highest level, as has been stated, was approximately 85,000,000 acre-feet. If the concentration of the water at this highest level, necessarily a matter of pure assumption, was 300 parts per million of dissolved salts, or about that of the present flow of Owens River, the total quantity of salts dissolved in this ancient body of water would have been about 35,000,000 short tons of anhydrous salts. This would be equivalent to a layer of the anhydrous salts 20 acres in extent and 1 foot deep, or with some water of crystallization and mother liquor perhaps the same area to a depth of several feet. It will be seen that the single filling and evaporation of a lake like that which formerly existed in the Panamint Valley would not necessarily result in the deposition of a large mass of salts when the lake dried up, but that such a lake must continue to concentrate waters of the character described for a long period in order to produce a very thick deposit of salines. That such a long-continued concentration actually took place in the Searles Basin is very certain, and there seems to be ample possibility that a similar concentration may have occurred in the Panamint Basin, though definite assumption of its occurrence is scarcely warranted.

GLACIAL AGE OF FORMER LAKES.

The correlation of the Quaternary lakes of Owens Valley and similar areas in the Great Basin with the stages of ice extension in the glacial epoch rests upon general considerations, although it is accepted by most geologists. The correlation of the maxima of Lake Bonneville and other lakes of the Great Basin with the stages of glaciation is considered at some length in the Bonneville monograph.[1] It is also generally agreed that the evidence of the glacial epoch in the West shows it to have consisted of at least two general stages of ice extension separated by a long period in which glaciation ceased. Since the ice last left the region the effects of weathering and erosion have been trivial, the morainic material of the last stage is but little disintegrated, and the contour of the latest of the glacial deposits has been only slightly altered.

Evidence of duality of the lacustral history in the Owens and related basins has not yet been recorded, but emphasis should be placed on the fact that the studies on which the present statements are based have been only of the most general character, and that much remains to be desired in the way of observation in these fields. By analogy with the recorded history of Lakes Bonneville, Lahontan, and Mono some or all of these basins are supposed to have had a dual lacustral history. By continuing the analogy the first of these stages is assumed to have been the longer, and the stage between inundations to have been probably more arid than the present day and several times longer than the second lacustral stage, although the waters may have temporarily risen during the second stage to their highest level. It is stated that the greatest expansion of the waters of the Mono Basin occurred subsequent to the last extension of the Sierra Nevada glaciers. It is reasonable to assume that the other lakes of the Great Basin attained their maxima at the same time.

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[1] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 265-318, 1890.

Whatever may be the true explanation of the glacial epoch in this part of the world, it is perhaps reasonable to assume that it represents a period of somewhat larger precipitation—that is, of greater humidity of climate. The accumulation of immense fields of snow and ice during certain stages of this epoch was undoubtedly followed by stages in which the melting of the snow and ice must have rapidly released very unusual volumes of water. Thus it is natural to suppose that the maxima of lake expansion may have been contemporaneous with or slightly lagging upon the stages of ice retreat, the waters being derived partly from the normal precipitation, but chiefly from the release by melting of the immense storage in the fields of glaciation. This affords an explanation for the apparent localization of the larger Quaternary lakes in the Great Basin, in their relation to the mountains of larger glaciation.

The basins in which these lakes were formed doubtless originated through displacements of the earth's crust in a region of such general aridity of climate that no continuous drainage to the sea has ever been established since they were formed. After the principal diastrophism by which the general configuration of these basins was established, followed a long stage of erosion and alluviation under arid conditions, during which broad delta-form deposits were built out from the mountains and the valley bottoms were filled to an unknown but probably great depth. Toward the close of this stage the lakes rose and filled certain basins, as has been stated, but since the waters have last receded relatively insignificant modification of the topographic forms has taken place. If the lake history of these basins has in fact been dual, as suggested, the question arises, Are the records of both inundations to be observed in the valley basins, or has the earlier record been so nearly obliterated that its traces are difficult to recognize or have not yet been identified?

The lake terraces described, including old high-level beaches and wave-distributed bowlder slopes, indicate in all their features the comparative recency of their formation and distribution. Talus of coarser rock fragments, angular and only slightly disintegrated, lies where it has been laid down by water action, below the upper shores in many parts of these basins, especially on the rocky slopes of the Searles Basin. These angular bowlders are piled in insecure positions, so that in places a shove of the foot will upset them and send them down the slopes, and yet in places the unbroken coatings of water-deposited tufa indicate that, as a matter of fact, the rocks have not been disturbed since they were last exposed by the receding lake waters.

The only clues to the supposed earlier and almost entirely obliterated lake record lie in the suggested tracing of shore lines and apparent wave-cut benches in both Searles and Panamint valleys at higher levels than the most distinct shores of the last and most evident stage, either indistinct or, if definite in outline, of forms so rounded as to be difficult of interpretation.

If, then, the conclusion is to be tentatively adopted that present evidences of the glacial lakes may be correlated in time with only the most recent stage of ice advance, as seems very likely, the question naturally arises, What may have been the lake history of this whole system during the earlier glacial stage? As a corollary it is also pertinent to inquire whether there may not also have been during the earlier stage saline deposition at least equal in magnitude to that resulting from the later desiccation.

PROSPECTS OF POTASH FROM THE DESERT BASINS.

When general interest was first aroused in the subject of potash in the West, attention was naturally directed to all natural accumulations of soluble salts, including "dry-lake" incrustations, residues or efflorescences, mixed mud and salts, and saline or alkaline lakes or well waters. In the testing of these deposits the public very generally participated. It was clearly impossible at that time to define or predict with certainty what classes of materials were most promising as a source of commercial potash, and there was no standard of comparison as to the percentage of potash necessary in a mixture or compound to make it commercially workable. At first the campaign of general, more or less haphazard, testing was entirely justified.

At the same time, however, the dominant idea in the exploration of the desert basins for saline and potash concentrations depended on the assumption of former saline lakes, whose waters by evaporation must have left their salts as massive saline residues. This idea has been referred to as the desert-basin saline hypothesis. At first it was very generally assumed that such lakes had existed in almost all the inclosed drainage basins, chiefly because these areas were alike in not having any present outlet, and the rise of their waters was supposed to have been due to a prevailing more humid climate. On further consideration, however, it is now believed more likely that these ancient lakes were not so widely distributed in the desert-basin region as was at first assumed, and it is even probable that large or persistent water bodies of this type were confined to relatively few areas. Therefore saline concentration in the desert basins may have been going on for long periods under intermittent lake or playa conditions, but the accumulation and deposition of salts in thick crystalline masses as a result of the desiccation of major saline lakes has perhaps been of comparatively rare occurrence. On this basis of reasoning random drilling in the desert basins in the search for large salt deposits is probably not justified from present evidence.

A further conclusion as to saline deposits in ancient lake basins seems warranted. The present ordinary lake waters of the region, such as those of Walker, Pyramid, and Winnemucca lakes, represent accumulations and concentration of tributary drainage waters for a very considerable period. In spite of this fact, if these lakes should dry up their total saline content if deposited as a residue on their dry bottoms would not form a very considerable mass of salts. It is therefore evident that the single filling of such lake basins is not evidence of any considerable saline accumulation in its waters, nor is even the existence of a concentrating reservoir through a long period of time very positive evidence of such a concentration. It therefore becomes important in attempting to estimate the chances of saline deposition from a given lake record to take due account of the probable duration of the concentration period, and this is likely to be a difficult factor to estimate.

The question whether potash would be segregated as a result of saline accumulation in shallow intermittent lakes and the resulting formation of lake deposits has also to be considered. It seems a justifiable conclusion that in such lake beds the potash and other salts would generally be so intimately mixed together or with mud or clay as to be a very unlikely source of commercially valuable materials. Before this idea was generally understood "potash" locations were staked in many of the desert playas and saline flats throughout the desert region. These locations were supported by the "discovery" of small percentages of soluble potash in the surface efflorescences or in the ground solutions of the playa deposits. It is now well known that potash is sparingly distributed in almost all natural saline deposits, and that its presence in small amount has therefore no special significance.

Perhaps the most important factor influencing the disposition of the soluble potash contained in natural drainage waters is the power which clays have of absorbing potash when brought into contact with its solution. It appears that herein lies the actual explanation of the apparent disappearance of much of the potassium salts from solutions or from the saline deposits collected in the desert basins.

Although the selective power of clays for absorbing potassium has long been recognized, its influence probably has not been fully appreciated in the discussions of the possible occurrence of potassium salts either in the desert-basin saline deposits or elsewhere in association with other salt deposits. Attention has been repeatedly directed to the low content of potassium as compared with sodium in the desert-basin salines, especially through the many analyses of brines, saline incrustations, and saline muds that have been made during the present investigations. It is significant that certain mud deposits associated with these natural salts have been found to yield unusual amounts of potash, which are not in water-soluble form as obtained in samples, but which readily become soluble on extraction with solutions containing ammonium chloride. The potash appears to be held in the mud either mechanically or in a loosely combined form, and it may have become fixed in this condition by the absorptive action of the muds on the concentrating saline solutions with which they have come into contact.

As a summary, it is probably safe to say that commercially valuable concentrations of potash are not to be looked for in the desert-basin deposits generally. In the first place, salines deposited by shallow intermittent lakes are not only so mixed with muds as to render their profitable recovery very doubtful, but such deposits are unlikely to retain on a large scale any considerable percentages of potassium in the soluble form. Only in the basins where large and deep saline lakes have existed and dried up under favorable conditions are massive deposits of salines free from mixture with mud to be looked for. Such conditions are rather exceptional. Probably few desert saline lakes have in fact dried up so free from the mixture of clay or other sediments that their water-soluble salts have retained the major portion of the potash originally present in the lake water.

The confident hope is still held out that these exceptional conditions exist in some places and that by good fortune or otherwise they may be revealed. It seems that in Searles Lake one such exceptional place has been found, and it is possible that there may be even larger and more valuable deposits still to be discovered.

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THE ROCHESTER MINING DISTRICT, NEVADA.

By Frank C. Schrader.

INTRODUCTION.

This report is based on a two weeks' visit made to the Rochester district and vicinity by the writer in May, 1913. A brief preliminary statement of the results of the reconnaissance was given to the press by the Survey in June, 1913.

Information generously given by mining companies, prospectors, engineers, and surveyors operating in the district has been of material aid in the preparation of this report.

The Rochester district, comprising about 25 square miles, is in west-central Nevada, in the southern part of Humboldt County. It is 9 miles southeast of Nixon, formerly Oreana, on the main line of the Southern Pacific Railroad, and 20 miles northeast of the town of Lovelocks. With both of these places it has daily freight, express, passenger, and mail service. A private branch railroad, the Nevada Short Line, extends from Nixon 5 miles across the lowland to the edge of the district.

The mining settlement of Fitting, formerly Spring Valley, lies a few miles to the northeast. South of Fitting, heading almost in the heart of the Rochester district, is American Canyon, noted for its large production of placer gold. The eastern part of the Rochester district was formerly known as the Sacramento district.

SURFACE FEATURES.

The Rochester district lies in the Humboldt Range, which is separated from the Montezuma or Trinity Mountains by the Humboldt Valley on the west, and from the Pahute Range by the Buena Vista Valley on the east. Most of these valleys, which are 8 to 10 miles wide, are of the flat-bottomed infilled Great Basin type.

The Humboldt Range, also called the Koipato Range in the reports of the Fortieth Parallel Survey,[1] is about 75 miles long and culminates on the north in Star Peak, 10,000 feet above sea level.

Near its middle point, in the latitude of Nixon and Rochester, the range is traversed by a low pass known as Cole Canyon (Pl.

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[1] Hague, Arnold, and Emmons, S. F., Descriptive geology: U. S. Geol. Expl. 40th Par., vol. 2, p. 713, 1877.

VIII), which divides it into two parts. The northern part, which has a northerly trend, Louderback[1] calls the Star Peak Range, and the southern part, which has a northeasterly trend, he calls the Humboldt Lake Range.

The Star Peak Range, in which the Rochester district lies, is fairly uniform in outline and has an average width of about 10 miles, its maximum width, which is about 15 miles, being in its southern part. Buffalo Peak, a huge mass nearly 8,400 feet in elevation, forms its southern end. The lowest pass in the range is Spring Valley Pass, 6,250 feet in elevation, or nearly 2,000 feet above the adjoining Humboldt Valley on the west.

The range is described by Hague[2] as a simple ridge with the axis near the center of the uplift, from which numerous canyons with broad basin-like heads, abruptly becoming narrower as they descend, extend down the mountain slopes at regular intervals. This description applies particularly to the Rochester district, where the heads of the lateral canyons almost coalesce.

The Rochester district lies in the southern part of the Star Peak Range, chiefly on its upper west slope, at elevations between 4,000 and 7,500 feet, as shown on the accompanying map (Pl. VIII). The area is mountainous but not rugged. Many of the canyons and ravines are passable for wagons, and most of them contain springs and wells of potable water.

The western part of the area is drained chiefly by Packard, Weaver, Rochester, Limerick, and Sacramento canyons, which enter Humboldt Valley, and Cole Canyon. The eastern part of the area is drained by Buffalo, South American, and American canyons and by Spring Valley, all of which open into Buena Vista Valley.

Within the district the crest of the range is represented by a relatively narrow ridge, about 6,600 feet in elevation. Its dominant feature is Nenzel Hill, an oval silicified knob, 3,000 feet long by 2,000 feet wide, at the head of Rochester and South American canyons. This hill rises 7,300 feet above sea level, or 500 feet above the adjoining portions of the divide. Lincoln Hill, a prominent landmark, which forms the end of the ridge bounding Rochester Canyon on the north, about 2⅜ miles west of Nenzel Hill, rises to an elevation of 6,600 feet.

HISTORY, PRODUCTION, AND MINING OPERATIONS.

The presence of mineral deposits in the Humboldt Range and the Rochester region was known half a century ago. Mining began in this part of Nevada about the year 1860 with the organization of the Humboldt district, on the northwest slope of Star Peak.[1] The Star Peak and Buena Vista districts were organized in 1861.[2]

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[1] Louderback, G. D., Basin range structure of the Humboldt region: Geol. Soc. America Bull., vol. 15, p. 294, 1904.

[2] Hague, Arnold, and Emmons, S. F., op. cit., p. 713.

Rochester Canyon took its name from some pioneers who in traveling overland from Rochester, N. Y., in the early sixties, prospected and mined at its mouth and are said to have examined most of the Humboldt Range from this locality southward. Some of the party worked the Montana lode in 1867, but soon after ceased operations. Supplies in those days were hauled overland from Sacramento and the rich ore was shipped by way of San Francisco to Swansea, Wales.

Evidences of former work in this district are the old Montana shaft near Lincoln Hill, sunk in the early sixties, and the Oro Fino shaft, in Gold Ridge, to the north (Pl. VIII). Rich float is said to have been discovered at Lincoln Hill by Tooper Bennett in 1888.

The first successful lead-silver smelter in Nevada was built and operated on Humboldt River just below Oreana to treat ore from the Montezuma mine, in the Trinity district.[2]

The discovery of ore in Nenzel Hill, the center of the present activity, was made a decade or more ago by Charles E. Stevens, a pioneer. Little work, however, was done at that time, and the ground reverted to the Government.

Later, in 1909, Joseph Nenzel and others relocated the ground, and a small shipment of ore was made in August, 1912, partly from the Causten tunnel, but mainly from talus or float. Large bodies of $50 to $60 ore were found in November, 1912, and in February and March, 1913, other bodies were opened in a second vein, at a depth of 130 feet. A carload and several smaller consignments of the relatively high-grade ore were shipped about Christmas, 1913, by Nenzel from the Causten, and by Frank Schick and Walt Moynaugh from the Weaver No. 2 claim. These shipments attracted attention to Rochester and the district was soon after visited by half a score of able mining engineers, nearly all of whom reported on it favorably.

In less than a month the hitherto desolate canyon had a population of more than 2,000 people and contained many substantial two-story buildings. Three town sites, Rochester (or Lower Town), Central Rochester, and East Rochester, were laid out, but these soon coalesced along a main street, 2½ miles in length, extending from Lincoln Hill to the base of Nenzel Hill. East Rochester, near the head of the canyon, at an elevation of 6,200 feet, soon became and has continued to be the principal camp.

Blocks 300 by 600 feet in area were leased and actively worked by experienced mining men and at the time of the writer's visit, in May,

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[1] Hague, J. D., Mining industry: U. S. Geol. Expl. 40th Par., vol. 3, p. 310, 1870.

[2] Ransome, F. L., Notes on some mining districts in Humboldt County, Nev.: U. S. Geol. Survey Bull. 414, p. 10, 1909.

1913, the development of the mines and the showing of ore made without aid of outside capital were remarkable. Ground was opened under six or eight leases to a depth of 130 feet by crosscut tunnels from 100 to 300 feet in length. About 2,000 tons of ore, averaging approximately $30 to the ton, had been mined and shipped, and much more, 100,000 tons it was said, was in sight. Nearly a score of properties were producing.

From March to November, 1913, inclusive, the known shipments from the district amounted to approximately 14,000 tons of ore having a total value of about $415,000, and the production for the year 1913 was approximately $500,000. In addition much milling ore had accumulated on the dumps. Of the ore shipped, 12,740 tons came from Nenzel Hill, chiefly from the Big Four, Codd, and Colligan leases, and averaged approximately $28 to the ton; 1,120 tons, averaging $50 to the ton, came from Packard; and 120 tons, which averaged $79 to the ton, came from the Buck and Charley lease, opposite Lincoln Hill. Some ore was produced also by Lincoln Hill and by the Limerick and Sunflower groups at the head of Rochester Canyon. The total production to September, 1914, is reported to be more than $1,200,000. In addition it is estimated that there had been developed in the district by that date more than 100,000 tons of milling ore, of which the Codd lease is credited with 50,000 tons averaging from $10 to $20 to the ton, the Four J lease with 20,000 tons, and the Rochester-Weaver mine with 15,000 tons. The average value of the ore produced during the 18 months ending June 30, 1913, is about $25 to the ton. Most of the ore mined has been sent to the Wabuska and Salt Lake smelters, although some was shipped to the Western Ore Purchasing Co., at Goldfield.

By December, 1913, development on most of the principal leases had extended to depths of about 300 feet, and the Causten tunnel, 630 feet in length, had reached a depth of 400 feet.

Two companies, the Rochester Mines Co. and the Rochester-Weaver Mining Co., own most of the developed ground on Nenzel Hill. According to the first annual reports of these companies, there was shipped during the year 1913 from the Rochester Mines Co.'s ground 14,726 tons of ore, averaging $25.04 to the ton, worth $368,770, the net profit being about $19,192, and from the Rochester-Weaver Mining Co.'s ground 953 tons, averaging $31.74 to the ton, worth $30,254.30.

At first the ore was chuted in sacks several hundred feet down the steep side of Nenzel Hill, thence stone-boated nearly a half mile farther to the head of the wagon road in Rochester Canyon, down which it was freighted to Nixon. Early in the spring of 1913, however, 6 miles of road of easy grade, suitable for auto trucks, was constructed jointly by the Rochester Mines Co. and the lessees, at a cost of

$10,000. This road, as shown on the map (Pl. VIII), extends up Limerick Canyon directly to the mines, almost to the top of Nenzel Hill (fig. 89). It enabled a saving of about $1 a ton haulage on the ore shipped during the year. Early in the summer it was connected at the mouth of the canyon with the new 5-mile branch railroad (the Nevada Short Line), built from Nixon across the soft lowland by the Rochester Hills Mining Co.

The railroad is now being extended up Rochester Canyon and will be operated as a common carrier. This road will greatly reduce the cost of ore shipment and freight. Arrangements will be made whereby trains will be run directly to the mines near the summit of Nenzel Hill. Under present conditions ore worth less than $22 to the ton can not be shipped with profit.

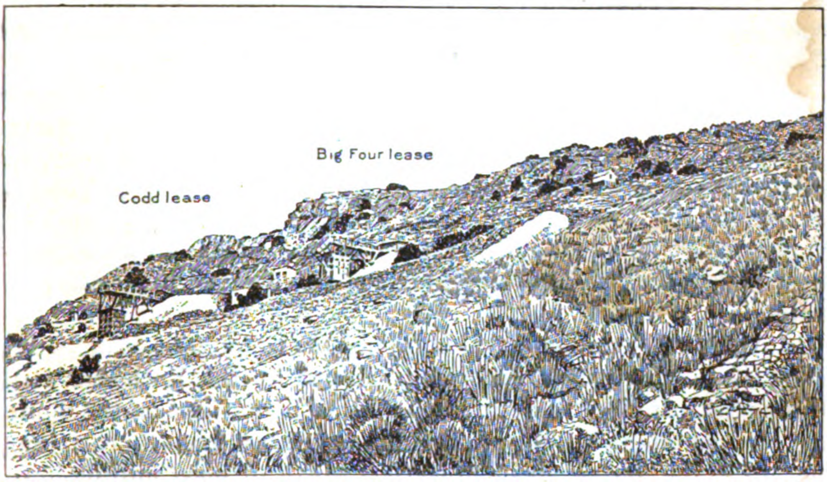

FIGURE 89.—Silicified croppings and mines on Nenzel Hill, Rochester district, Nev., looking east-northeast.

In 1913 the production was nearly all made by lessees. The lessee system has proved very satisfactory to all concerned, and probably about twice as much development has been made thus as would have been made by the owning companies themselves in the same length of time. With the expiration of the leases, however, the companies mostly plan to operate the Nenzel Hill mines themselves. A consolidation of the five or six principal properties is under consideration, as the relations of the ore bodies and the topography of the hill are admirably adapted to work under one management.

According to the report of the Rochester Mines Co. for 1913, the proceeds from each ton of ore were apportioned as follows:

Wagon haulage	$4.43
Railroad freight and treatment	8.70
Lessees' share	9.79
Company's royalty	2.12

A very complete 100-ton cyanide plant is now being built, at a cost of $100,000, by the newly organized Rochester Consolidated Mining & Milling Co. The plant is located in the southeastern part of the district, in Rochester Canyon, near the Rochester and Packard road forks, on the railroad, about half a mile below Lower Town. At the outset ore from the Nenzel Hill mines will be delivered at the plant by a 2-mile aerial tram.

In this plant a Blake crusher, a 10-stamp mill, and tube mills will be used for crushing. The plant, although primarily intended for treating ore from the Rochester mines group, will also do custom work for the various mines of the district, which will make the large reserves of milling ore accumulated in the district available for treatment. The plant is expected to be in operation by January 1, 1915. Water for the plant is to be brought by pipe line from Hardesty Canyon, 5 miles distant, near Packard. The machinery is to be driven by hydroelectric power supplied from the Lahontan dam.

Shipment mill tests made of the ores to be treated by the process to be here used are said to indicate a recovery of about 95 per cent of the silver and 92 per cent of the gold from the sulphide ores and 85 per cent of the silver and 90 per cent of the gold from the oxidized ores. From the 200-foot level down the ores are said to be nearly all sulphide.

In April, 1914, the camp was shipping 130 to 150 tons of ore a day, about 40 tons of which was being shipped by the Rochester Hills Mining Co. In May there was reported to be in sight on the dumps and blocked out at the Nenzel Hill mines 100,000 tons of ore averaging $15 to the ton, or about $1,500,000 worth of good milling-grade ore. For each ton of shipping ore taken out about 4 tons of low-grade or $15 milling ore is developed. The Nenzel Hill ore, it is estimated, can be mined for about $3 a ton and milled at a cost of about $6 a ton.

Ample water for milling and domestic use can be brought by gravity, it is said, from Lee Springs, a few miles to the north. At the time of the writer's visit sufficient water could also be pumped from the basin at the east base of Nenzel Hill, where several strong springs issue into South American Canyon. This water apparently owes its source largely to the easterly dip of the rocks in the adjoining axis of the range. The quantity stored here that could be relied on in the dry season depends mainly on the volume of the alluvial deposits, which fill the basin and seem to have considerable thickness. Springs occur also in the neighboring American, Limerick, and Weaver canyons. Thus far the water supply for Rochester has been obtained from wells 10 to 40 feet deep sunk in the alluvial gravels of Rochester Canyon. The supply for Packard is drawn from Black Knob Spring, about a mile and a half away, in Cole Canyon (Pl. VIII).

The climate of Rochester is ideal in summer, but the winters are severe for Nevada. The hills are generally free of snow in early April. High winds are common, as are also thunderstorms or cloudbursts, which late in May, 1913, flooded the canyons with short-lived torrents.

Grass and scattered trees of the western juniper grow on the hillsides.

At the time of the writer's visit, in May, 1913, the district had a population of about 1,000 people, of whom 700 were in East Rochester, where 200 miners were at work in Nenzel Hill and 250 were in Lower Town, and Packard, the newest settlement, only a few weeks old, at the south base of Packard Hill, had a population of about 100, which was daily increasing. Panama, on the northeast near Spring Valley Pass, in the head of Limerick Canyon, a mile and a half over the ridge from Rochester, contained a score of people.

Nixon, formerly little more than a watering station in the desert for Southern Pacific trains, had become a small town.

GEOLOGY.

ROCKS OF THE REGION.

GENERAL FEATURES.

Hague[1] described the Humboldt Range as consisting of an Archean nucleus, surrounded and unconformably overlain by Triassic strata of great thickness, these in turn being overlain by Jurassic beds, which, along the base of the range and locally elsewhere, are steeply tilted, broken, and associated with masses of Tertiary rhyolite and basalt, and with poorly exposed Miocene beds called the Truckee group. The Archean and Triassic rocks were described as sparingly cut by Mesozoic dikes, chiefly diabase. The Triassic rocks were separated by Hague into two groups, which in ascending order he designated the Koipato and Star Peak "series," but which are here termed formations.

KOIPATO FORMATION.

The Koipato formation, so called from the Indian name of the Humboldt Range, occupies, according to the map of the Fortieth Parallel Survey, approximately the north half of the southern half of the Star Peak Range, including the Rochester district. It forms a belt 8 miles wide, trending from Cole Canyon diagonally northeastward across the range to Unionville, whence, as a narrow strip, the formation is shown as extending 9 miles northward along the east base of the range. Similarly, along the west base, a narrow tongue of the Star Peak formation is mapped as extending southward to Sacramento Canyon.

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[1] Hague, Arnold, and Emmons, S. F., op. cit., p. 714.

The Koipato formation was supposed by Hague to consist chiefly of metamorphosed silicified sedimentary rocks, beds of quartzite overlain by interstratified beds of limestone, quartzite, and "felsitic porphyroids." It was referred to the Triassic and regarded as of the same geologic age as the lower members of the "Red Beds" of the Rocky Mountain region. Its thickness was estimated at 6.000 feet.

STAR PEAK FORMATION.

In or near the Rochester district the Star Peak formation succeeds the Koipato formation on the southeast. It occupies mainly the southern fourth and the northern half of the Star Peak Range. Its thickness was estimated by Hague at 10,000 feet.

According to the section compiled by Ransome[1] from Hague's description it consists of the following members:

Section of the Star Peak formation, Star Peak Range, Nev.

[Compiled from the description by Arnold Hague.]

	Feet.
Quartzite and overlying limestone	4,000-5,000
Massive limestone	1,800-2,000
Black arenaceous slates	200- 300
Slaty quartzites alternating with greenish schistose rocks	1,500
Limestones, dark, almost black at the base, passing up into gray and blue varieties	1,200-1,500

Ransome[2] also writes:

> The Star Peak formation is noted for its abundant Middle Triassic vertebrate and invertebrate fossils, which have been described by Gabb,[3] Meek,[4] Hyatt and Smith,[5] and J. C. Merriam.[6] * * * Hyatt and Smith[7] [and Smith[8]] state that the Upper Triassic is also represented in the Humboldt Range, and list half a dozen fossils. The beds containing them are said to be unconformably overlain by limestone containing Jurassic forms.

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[1] Ransome, F. L., op. cit., p. 31.

[2] Idem, p. 32.

[3] Gabb, W. M., Paleontology: California Geol. Survey, vol. 1, pp. 19-35, 1864.

[4] Meek, F. B., Paleontology: U. S. Geol. Expl. 40th Par., vol. 4, pt. 1, pp. 99-129, Pls. X and XI, 1877.

[5] Hyatt, Alpheus, and Smith, J. P., The Triassic cephalopod genera of America: U. S. Geol. Survey Prof. Paper 40, pp. 21-23, Pls. XXII-XXV, 1905.

[6] Merriam, J. C., Triassic Ichthyosauria: California Univ. Mem., vol. 1, No. 1, pp. 18-19, 1908.

[7] Hyatt, Alpheus, and Smith, J. P., op. cit., p. 26.

[8] Smith, J. P., The Middle Triassic marine invertebrate faunas of North America: U. S. Geol. Survey Prof. Paper 83, 1914.

Later and more detailed work than that of the Fortieth Parallel Survey has shed more light on the geology of the range and led to certain revisions in the interpretation of the geologic phenomena and classification of the rocks. Of these revisions the following are the more important:

According to Louderback,[1] the supposed Archean nucleus exposed in Rocky Canyon, 7 miles north of Nixon, is post-Triassic intrusive granite with associated contact-metamorphic phenomena in both the granite and the host rocks.

According to Ransome,[2] the Koipato formation as a whole is a volcanic complex, consisting chiefly of rhyolitic flows, in which nonvolcanic sediments, including limestones, form only a subordinate part. With this view, the determinations of the rocks in the Rochester district by Jones[3] and others, including the present writer, are essentially in accord.

The boundary between the Koipato and Star Peak formations, which is erroneously represented on the Fortieth Parallel Survey map as passing through Nenzel Hill, apparently lies well to the east of Nenzel Hill and of the area shown on the accompanying map (Pl. VIII), but, as Ransome has pointed out, the place of division between the two formations lacks accurate definition. On the northeast the rhyolites of the Koipato formation and of Nenzel Hill extend about a mile and a quarter down American Canyon to the 5,740-foot contour, where they are succeeded by greenstone and sedimentary rocks apparently belonging to the Star Peak formation. Approximately the same is true of their extension down South American Canyon, on the east, and into the mountains forming the crest of the range, on the southeast.

VALLEY FILL.

The intermontane valley fill, particularly that between the mouth of Rochester Canyon and the railroad west of it, consists chiefly of the deposits of the Quaternary Lake Lahontan, in large part overlain by recent alluvium, talus, and débris washed from the neighboring mountains. As seen at Nixon and elsewhere, the lake beds consist chiefly of very fine, soft silts, over which freighting by team is difficult and expensive.

STRUCTURE.

The general structure of the Star Peak Range is described by Hague[4] as that of an anticlinal fold extending diagonally across the topographic uplift, striking about N. 30° E. and crossing the range obliquely at Spring Valley Pass.

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[1] Louderback, G. D., op. cit., pp. 317–318.

[2] Ransome, F. L., loc. cit.

[3] Jones, J. C., Geology of Rochester, Nev.: Min. and Sci. Press, vol. 106, pp. 737–738, 1913.

[4] Hague, Arnold, and Emmons, S. F., op. cit., pp. 716, 728.

In a broad way this anticlinal structure appears to extend, so far as the present writer's observations show, through the southern part of the range.

Louderback[1] regards the Star Peak Range as an elevated and eastward-tilted fault block of pre-Cretaceous rocks similar to the Humboldt Lake Range, which he has carefully studied. The main fault along the west base of the range is regarded by him as the same as that which, extending through Cole Canyon, separates the Star Peak and Humboldt ranges.

ROCKS OF THE ROCHESTER DISTRICT.

The Rochester district lies in an area mapped by the Fortieth Parallel Survey as occupied by the Koipato formation. As has been already stated, later work has shown that this formation is a volcanic complex consisting chiefly of rhyolitic rocks, but within the district it contains also limestone, shale, quartzite, and some greenstones of igneous origin.

The rocks having the largest areal extent near Rochester and those most closely associated with the ore deposits are light colored and are chiefly rhyolite or rhyolitic, but with them are included also some quartz latite, dacite, andesite, and altered quartz porphyry. As shown on the accompanying map (Pl. VIII), these rocks occupy almost the whole of the eastern part of the Rochester district and extend westward to Lincoln Hill.

The formation consists of superimposed flows of rhyolite and rhyolitic lavas, with intercalated beds of tuff, breccia, and obsidian. In places, as at the head of Rochester Canyon, the rocks appear to be agglomeratic. The rhyolites are locally very variable in texture, changing abruptly from dense felsitic lavas to coarse porphyries. Flows in Nenzel Hill and on the Sunflower ground, farther south, show some flow banding or lamination.

In Nenzel Hill and on the divide a mile and a half to the north, at the head of Limerick Canyon, the rocks dip about 30° E. and are transversely sliced by a very pronounced sheeting, the dominant structure of the region, which dips about 60° W. The rocks are cut into sheets or slices from a few inches to 5 feet or more in thickness. This sheeting is locally accompanied by more or less profound parallel shearing and by the development of schistosity, which is best seen on the weathered edges of the sheets. Slickensiding and grooving are also very common. Locally, at least, as shown in the Causten tunnel, there is another pronounced sheeting with a dip to the north and a less conspicuous one to the east-southeast. The rocks and the

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[1] Louderback, G. D., op. cit., pp. 316–322.

ore zone are also cut by a nearly vertical east-west cross jointing into slices from 1 foot to 4 feet in width.

Nenzel Hill appears to be composed almost wholly of the rhyolitic complex. The rocks there are considerably faulted. Besides the sheeting in the north end of the hill the rocks, locally at least, are traversed by a system of close fracture planes or joints that strike N. 30° W. and another system that strikes approximately at right angles to this structure.

In Packard Ridge, 2 miles south of Nenzel Hill, as shown in figure 90, the rhyolitic rocks dip 50° WNW., apparently conformably beneath some rather thin bedded and less disturbed arenaceous limestones and shales.

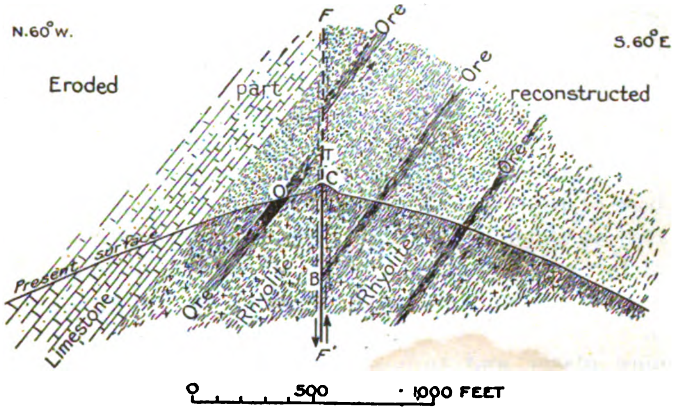

FIGURE 90.—Diagrammatic cross section of Packard Ridge, Rochester district, Nev., showing position of the principal ore deposits. Looking N. 30° E. C, Craggy croppings of silicified schistose rhyolite; O, present main ore body, 30 feet wide and 1,200 feet long; F–F', fault fissure; BCTO, probable course of ore-depositing solutions.

Similarly at the west base of Lincoln Hill, 3 miles west of Nenzel Hill, the rhyolites appear to pass conformably beneath the same limestone-shale series as at Packard, which here dips 20°–60° WSW. In the Packard and Lincoln Hill exposures, however, the layering in the rhyolites is obscure and has been less definitely determined than in Nenzel Hill.

At Packard the sedimentary beds are unaltered and appear to have been deposited on the rhyolite. At Lincoln Hill, however, the limestones, which are leaden to dark bluish gray and are rather thick bedded, are in part metamorphosed. They are partly schistose, are silicified, and contain diopside, actinolite, garnet, and other contact-metamorphic minerals, developed near the rhyolite, which indicates that the rhyolite may be intrusive and later than the limestones, but the actual contact of the two formations is not sufficiently well exposed to prove that the metamorphic phenomena were caused by the rhyolite.

In this connection it may be noted that rhyolite dikes, to which attention was called by Reid,[1] also intrude the schists and other rocks about a mile north of Spring Valley Pass, and the lower part of Limerick Canyon, according to Ransome,[2] lies in granite porphyry which has the appearance of being intrusive.

A little farther from the Lincoln Hill contact the limestone beds are rich in poorly preserved fossil remains, some of which G. H. Girty has provisionally determined as crinoid stems and remains of ammonites, probably of Triassic age.

The sedimentary rocks here described extend up Weaver Canyon and the gulch bounding Packard Ridge on the west, but their boundary in these localities has not been traced.

Exposures adequate for the determination of the thickness of the rhyolite series do not occur in the district. From the top of Nenzel Hill, however, to a point below the Causten tunnel the rocks have a thickness of at least 500 feet. From outcrops extending interruptedly farther down the slope in the head of Rochester Canyon it is very probable that the thickness may exceed 1,000 feet. Similarly, from exposures extending across the district (Pl. VIII) to the east base of Lincoln Hill and the ridge to the south, the thickness is estimated at about 2,000 feet. This estimate, however, makes no allowance for a possible duplication of layers by faulting or for changes in structure, such as may occur in a region so highly disturbed.

The more glassy and tuffaceous varieties of the rhyolite rocks occur in the upper part of Nenzel Hill, in thin layers, some of which resemble beds of dense quartzite. Here a dark gray speckled, medium-grained facies, locally called granite on Crown Point claim No. 1, in the northeast slope of the hill, is really a tuff or flow breccia and contains considerable pumiceous glass and fine dust-like volcanic detritus.

The rocks, particularly in the mineralized areas as at Nenzel Hill, are in general silicified, devitrified, and sericitized. To silicification Nenzel and Lincoln hills and Packard Ridge owe the preservation of their forms, which rise above the surrounding surface.

As stated by Jones,[3] however, the rocks retain enough of their original character to be recognizable in the field and in places they show relatively well preserved phenocrysts of quartz.

Under the microscope the rhyolites are found to consist essentially of a microcrystalline to glassy groundmass in which are a few phenocrysts of quartz and orthoclase, with well-developed microperthite and microcline, in some varieties, and rarely a few small foils of altered pale-brown biotite or of green chlorite derived from the biotite. The rocks generally show approximate parallelism in the arrangement of their constituents, which in some places is clearly fluxion banding but in others is obscure and may have been effected by pressure. The latter view is supported by wavy extinction, which is common in the quartz phenocrysts. Spherulitic structure is common in the specimens from Packard.

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[1] Reid, J. T., oral communication.

[2] Ransome, F. L., op. cit., p. 36.

[3] Jones, J. C., op. cit., p. 738.

The hydrothermal alteration of the rocks increases with nearness to the veins and ore deposits. In some places, both groundmass and phenocrysts, notably the feldspar, are completely replaced, or nearly so, by secondary silica, which, as seen in thin section, forms veinlets, stringers, and irregular crystalline patches throughout the slide, encircles the quartz phenocrysts as aureoles, and lines druses.

Apparently almost contemporaneously with the process of silicification there was developed in some rhyolites considerable secondary orthoclase, and, in some facies, microperthite and microcline.

Sericitization is also general and has proceeded to advanced stages. Some orthoclase phenocrysts are almost wholly replaced by sericite and kaolin. A thin section from the Colligan tunnel is threaded by veinlets and seams of sericite, and one of a glassy porphyritic rock from Packard, besides containing patches of this mineral, shows a network of irregular veinlets and seams of it.

In the more mineralized areas, the rocks commonly contain finely disseminated pyrite, which weathers to limonite and hematite and tints the rocks light rusty brown.

Similar rocks occurring in Cottonwood Canyon, 7 miles to the north, were analyzed for the Fortieth Parallel Survey,[1] and Jones[2] regards one of the analyses (B, in the subjoined table) as indicating the general composition of the rocks in this area.

Analyses of rhyolites from the Humboldt Range.

	A.	B.	C.
SiO_2	76.80	74.74	87.00
Al_2O_3	11.64	14.14	9.6
Fe_2O_3	1.10	.79	1.2
MgO	Trace	.39	Trace.
CaO	.43	1.51	
Na_2O	2.53	.92	
K_2O	6.69	5.29	
H_2O+	.77		
S			.2
Li_2O	Trace.		
Ignition		1.88	
	99.96	99.66	98.00

A. Typical rhyolite from the Mopung Hills, forming the southern end of the Humboldt Range. Inserted for purposes of comparison. M. R. Woodward, analyst. U. S. Geol. Expl. 40th Par., vol. 2, p. 736, 1877.

B. A brownish-gray rock containing both feldspar and quartz, from Cottonwood Canyon. B. E. Brewster, analyst. U. S. Geol. Expl. 40th Par., vol. 2, p. 722, 1877.

C. Partial analysis of a specimen from the silicified hanging wall, a few feet from the ore body in Codd lease in Nenzel Hill. W. S. Palmer, analyist, Mackay School of Mines, Reno, Nev. Min. and Sci. Press, vol. 106, p. 738, 1913.

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[1] Hague, Arnold, and Emmons, S. F., op. cit., p. 722.

[2] Jones, J. C., loc. cit.

Analysis C is regarded by Jones as illustrating the increase in silica near the ore bodies, some of which, as he states, consist almost wholly of quartz that has replaced the rhyolite.

Analyses B and C agree well in their more important constituents with that of the typical rhyolite, A, except that C, as was to be expected, is high in silica and B is low in sodium, which from the alteration that has taken place in the rock is not surprising.

The areas shown on the map as greenstone, one three-fourths of a mile northeast of Lincoln Hill and the other at Spring Valley Pass, contain chiefly highly altered, compressed, and partly schistose dark rocks, which appear to be chiefly metamorphosed andesite porphyry, or possibly in some places diorite porphyry, with some basalt or diabase. There is also some light-greenish sericitic and micaceous quartz schist. The darker diabasic rocks contain some finely disseminated pyrite, mainly in or associated with the altered augite phenocrysts as shown in specimens from Sacramento Canyon and Spring Valley Pass.

In the schist in the west slope of Lincoln Hill, which he calls mica-tourmaline schist, the tourmaline, according to Jones,[1] is a pink variety or rubellite, containing, however, the predominating alkali soda rather than the usual lithium, and mica that is associated with it also appears to be the soda mica, paragonite.

The andesitic rocks, in which the ferromagnesian minerals are highly altered, contain residual phenocrysts of calcic plagioclase and are traversed by veinlets of secondary quartz and calcite. The diabase, in part at least, is less altered dynamically than the other rocks and probably represents later intrusive sheets and dikes.

ORE DEPOSITS.

LODES.

GENERAL FEATURES.

The deposits of the Star Peak Range in general are silver-gold ores, characterized mineralogically by the presence of one or more of the sulphantimonites. They occur chiefly in the Star Peak formation in structurally favorable places, and although rich near the surface have not proved persistent to great depth. To these statements the Rochester ore deposits, geologically and in part mineralogically, form an exception. They are chiefly antimonial silver and gold bearing deposits but they occur mainly as replacement deposits in the sheeted rhyolite and are irregular, lodelike, or veinlike in form. Their material is chiefly quartz. The associated minerals observed are given in the table on pages 340–341.

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[1] Jones, J. C., loc. cit.

The deposits occur in two north-south belts, each about a mile in width—the Nenzel Hill belt on the east and the Lincoln Hill belt on the west. The belts parallel the range and approximately the dominant structure of the country rock, to which the deposits in large measure conform.

Minerals of the Rochester district and vicinity, Nev.

Mineral.	Chemical composition.	Form of deposit.					Origin of mineral.		Locality.										Remarks.
		Contact metamorphic.	Regional metamorphic.	Replacement.	Veins.	Placer.	Primary.	Secondary.	Nenzel Hill.	Lincoln Hill.	Packard.	American Canyon.	South American Canyon.	Spring Valley.	Sacramento Canyon.	Relief mine.	Pole Canyon.	Limerick Canyon.	
Actinolite	Metasilicate of calcium, magnesium, and iron.	×	×						×										In limestone and greenstone schist.
Alunite	Hydrous sulphate of aluminum and potassium.			×				×	× ?		×								Sparingly in ore and rhyolite.
Argentite	Silver sulphide			×?	×		×	×	×	×	×			×		×?	×		In ore.
Arsenopyrite	Sulpharsenide of iron			×			×										×		In replacement quartz.
Azurite	Blue hydrous basic cupric carbonate				×			×		×				(*a*)	×				From chalcopyrite.
Barite	Barium sulphate				×		×							×	×			×	Forms numerous veins in greenstone.
Bindheimite	Hydrous antimonate of lead			×	×		×		×		×								Associated with ore.
Biotite	Black mica, hydrous silicate of iron, magnesium, and potassium.						×		×	×	×	×		×	×	×	×		Sparingly in rhyolite and andesite.
Bromyrite	Silver bromide				×			×	×?	×				×?		×	×?		As ore mineral.
Calcite	Calcium carbonate			×				×		×	×			×		×			With quartz as gangue mineral.
Cerargyrite	Silver chloride				×			×	×	×	×			×		×	×	×	As ore mineral.
Cerusite	Lead carbonate				×			×									×		Fibrous in quartz druses associated with galena.
Chalcocite	Cuprous sulphide			×	×			×						×					Sparingly in McIlravy prospect.
Chalcopyrite	Copper-iron sulphide ($CuFeS_2$)				×		×?		×	×				×			×		In barite-quartz gangue.
Chlorite	Hydrous silicate of aluminum, iron, and magnesia.				×			×	×	×	×			×	×	×	×	×	In barite veins; in altered rhyolite and other igneous rocks.
Chrysocolla	Hydrous copper silicate				×			×						×					McIlravy prospect.
Cinnabar	Red mercury sulphide			×?	×	×	×	×?			(*b*)	×	×						Mainly in kaolinized rhyolite.
Diopside	Magnesium calcium silicate	×					×			×									In limestone altered by contact metamorphism.
Electrum	Argentiferous gold			×	×		×										×		Important source of gold and silver.
Epidote	Basic calcium-iron-aluminum orthosilicate.	×	×				×?	×	×	×				×	×		×		In limestone and altered igneous rocks.
Fluorite	Calcium fluoride				×		×										×		Sparingly present in quartz gangue of gold-silver-lead ore.
Galenite	Lead sulphide				×		×	×?	×	×		×		×		×	×	×	Is ore mineral at Pole Canyon.
Garnet (grossularite?).	Calcium-aluminum orthosilicate	×	×?				×			×									In silicified limestone.

[a] Stuart-Lee mine, McIlravy prospect.

[b] 2 miles south.

Gold	Native element	....	....	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	In lode and placer deposits, and alloyed with much silver at Pole Canyon.
Hematite	Iron sesquioxide	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	Mostly in vein and lode croppings.
Jamesonite?	Lead sulphantimonite	....	....	....	×	....	....	×	×?	×?	....	....	....	....	....	....	....	....	
Kaolinite	Hydrous aluminum silicate	....	....	....	....	....	....	×	×	×	×	×	×	×	×	×	×	×	Common in altered igneous rocks, especially the rhyolite.
Limonite	Iron hydroxide	....	....	....	....	....	....	×	×	×	×	....	....	×	....	×	×	×	In vein and lode croppings and altered igneous rocks.
Malachite	Green hydrous basic copper carbonate	....	....	....	×	....	....	×	×	×	....	....	....	×	....	×	×	....	From chalcopyrite and cupriferous pyrite.
Marcasite	Iron disulphide	....	....	....	×	....	×?	×	....	....	....	....	....	....	....	....	×	....	In replacement quartz and altered igneous rocks.
Microcline	Potassium-aluminum disilicate (potassium feldspar, triclinic).	....	....	....	....	....	×	×	×	×	×	....	....	×	....	....	×	×	Primary in rhyolite, secondary in silicified rhyolite.
Microperthite	Silicate of aluminum and potassium	....	....	....	....	....	×	×	×	×	×	....	....	×	....	....	×	×	Do.
Molybdenite	Molybdenum sulphide	....	....	....	....	....	×?	....	....	....	....	....	....	....	....	....	....	×	Empire mine.
Muscovite	White mica; hydrous silicate of potassium and aluminum.	....	....	....	×	....	×	....	×	×	....	....	....	....	....	....	....	....	Also in rhyolite.
Opal	Hydrous silica	....	....	....	....	....	×	×?	×	×	....	....	....	....	....	....	×	....	Coating joint planes in rhyolite.
Orthoclase	Potassium feldspar; potassium-aluminum disilicate; monoclinic.	....	....	....	....	....	×	×	×	×	×	....	....	×	....	....	×	....	Secondary in silicified rhyolite.
Paragonite	White mica; hydrous silicate of sodium and aluminum.	....	....	....	....	....	....	×	....	×	....	....	....	....	....	....	....	....	In greenstone schist.
Proustite	Ruby silver, sulpharsenite of silver	....	....	....	×	....	×	×	×	×	....	....	....	×	....	×	×?	×	In ore.
Psilomelane	Hydrous manganese manganate	....	....	....	×	....	....	×	×	×	×	....	....	×	....	....	×	....	Mostly in vein and lode croppings.
Pyrargyrite	Silver sulphantimonite	....	....	....	×	....	×?	×	×	×	×?	....	....	....	....	×?	×	....	Ore mineral.
Pyrite	Iron disulphide	×	×	×	×	....	×	×	×	×	×	×	....	×	×	×	×	×	Common but not abundant.
Pyrolusite	Manganese dioxide	....	....	....	×	....	....	×	×	×	×	....	....	×	×	×	×	....	Mostly in vein and lode croppings.
Pyrrhotite	Magnetic pyrite; iron sulphide ($Fe_{11}S_{12}$)	....	....	....	×	....	×	....	×	....	....	....	....	×?	....	....	....	....	Sparingly in East vein, Roy Ridge mine and Spring Valley.
Quartz	Silica	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	Common in nearly all rocks and deposits.
Rubellite	Lithia-bearing tourmaline	....	....	....	....	....	....	....	....	×	....	....	....	×	....	....	....	×	In greenstone schist.
Sericite	A form of muscovite	×	×	×	....	....	....	×	×	×	×	....	....	×	....	....	×	×	Abundant in hydrothermally altered rhyolite.
Silver	Native element	....	....	×	×	....	×	×	×	×	×	....	....	×	....	....	×	×	As wire silver and similar forms and alloyed with gold at Pole Canyon.
Specularite	Iron sesquioxide	×	×	....	×	....	×	....	×	×	....	....	....	×	....	....	×	....	
Sphalerite	Zinc blende, zinc sulphide	....	....	....	×	....	×	....	×	×	....	×	....	×	....	....	×	×	
Stibnite	Antimony sulphide	....	....	....	×	....	....	....	....	....	....	....	....	×	....	....	....	×	
Talc	Hydrous magnesium metasilicate	....	....	×?	....	....	....	....	....	....	×	....	....	....	....	....	....	....	As product of weathering associated with the deposits.
Tetrahedrite	Gray copper. Sulphantimonite of copper.	....	....	....	×	....	....	....	....	....	....	....	....	×	....	....	....	....	
Tourmaline	Complex silicate of aluminum, boron, etc.	....	×	....	×	....	×	×	....	×	....	....	....	×	....	....	....	....	In quartz associated with native gold.

NENZEL HILL BELT.

The Nenzel Hill belt of deposits, which is by far the most important, extends from Packard northward to Spring Valley Pass, its length being nearly 5 miles. Nenzel Hill, which contains the most valuable part of the deposits, is situated near its middle point.

NENZEL HILL ORE DEPOSITS.

The ore deposits of Nenzel Hill occur as replacement veins and allied deposits, in part composed of small veins and stringers of quartz, but chiefly altered, silicified, and replaced rhyolite. The ores contain chiefly silver, but carry also gold, which in some of the ore amounts to 60 per cent of the value.

The croppings are locally prominent, generally iron stained, and commonly constitute rich shipping ore.

The quartz is locally porous, cellular, and drusy. The vugs are small, generally parallel, lenslike in outline, and are lined with fine comby quartz, whose crystals may nearly coalesce, leaving only a narrow, irregular watercourse along the median plane. Some of the quartz is brecciated, crushed, or laminated, and in places ore minerals have been deposited in the fractures. Some faulting along the veins is shown by the local occurrence of 6 or 8 inches of gouge on the footwall.

The trend and general relations of the more important veins and lodes are shown in figure 91. They vary from a few feet to 40 feet or more in width and range from 100 to 3,700 feet in length. Collectively they extend for nearly a mile. The known deposits are mostly on ground owned by the Rochester Mines Co. and the Rochester-Weaver Mining Co. They comprise 12 claims and are commonly known as the Nenzel group.

The deposits occur along fissures and shear zones and locally within fissures. They follow approximately two of the sheeting or joint systems described under the heading "Geology" (p. 334). One set trends approximately north, and the other N. 30° E. The latter, as indicated by development to date, is much the stronger and more important system, and is apparently also the younger. Its veins have a horizontal length of nearly 4,000 feet, and some of them have a known vertical range of 500 feet or more. In places they join or intersect veins of the northward-trending system. Both systems dip steeply to the west at angles of 60° or more. A few short and relatively unimportant veins occur on the east-west sheeting.

MINING DEVELOPMENT.

The deposits are opened mainly on the Rochester Mines Co.'s ground, where more than 7,000 feet of work has been done, mainly on the west or main Nenzel Hill vein, which belongs to the northeast-southwest system and has a length of nearly 3,000 feet. On the Crown Point No. 1 claim, workings on the Codd and the Big Four or Platt leases, shown in Plate VIII (p. 334) and figure 89 (p. 329), have attained a depth of 300 feet or more, and levels have been run at intervals of 50 feet. Here at the time of visit the ore zone, as exposed to the depth of about 100 feet, had a width of 32 feet. It showed two veins of ore, each 6 to 8 feet wide, averaging $30 to the ton. The ore then exposed in some portions of these veins averaged several hundred dollars to the ton, and some was even richer. The entire zone, as then exposed, was said to average $12 to the ton. The two veins were composed of numerous irregularly dipping stringers of ore-bearing quartz, separated by silicified rhyolite, which in many places was also ore. The quartz and vein material in general was crushed and a considerable portion of it was moderately well banded.

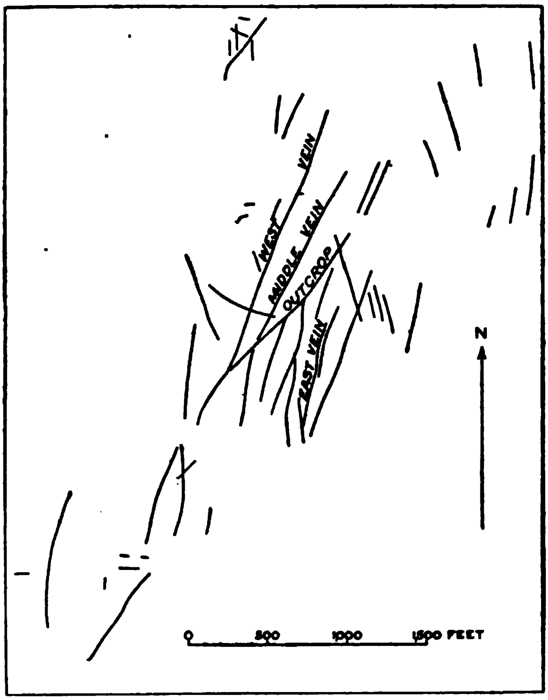

FIGURE 91.—Plan of the principal lodes and veins in Nenzel Hill, Rochester district, Nev.

On December 1, 1913, the general conditions just described were authentically reported to continue to the bottoms of the mines, with no indication of diminution in the quantity or quality of the ore. The workings have been in good ore from the surface down. In the lower part of the Big Four mine the lessees at the end of the year 1913 had opened up a block of ground 110 feet deep by 80 feet long. At the same date the Codd lease, developed by about 2,500 feet of work and credited with a production of over 9,000 tons of ore, had an ore shoot known to be 150 feet deep and 160 feet long.

In March the operators of the Big Four mine reported 3,000 tons of ore in the stopes ready for shipment. Late in April they were stoping a width of 7 feet of good shipping ore just beneath the 50-foot level stope, which last autumn produced $100,000, and on the 160-foot level south and on the lower levels stoping, raising, and sinking showed that the ore body in places has a width of 14 feet.

In the Codd mine, late in January, 1914, an ore shoot was opened on the hanging-wall side of the 150-foot level. This averaged about $65 to the ton, of which about $6 was in gold. This mine, from the surface down to the bottom level, still contains large bodies, 4 to 14 feet wide, of milling ore, amounting to about 25,000 tons and averaging about $14 to the ton.

Late in April, 1914, the shaft on the Codd lease had attained a depth of 500 feet, and good ore was being mined from the 320-foot level north, and in May the main vein, with good ore in the east crosscut on this level, was struck. The workings were being connected with the main Causten level, which is 400 feet below the outcrop of the vein.

According to later reports, on the 425-foot level a width of 10 feet of the vein averages $20 and 3 feet of it about $35 to the ton, and much $25 ore is said to be blocked out. Here also a 40-foot crosscut to the east from the bottom of the shaft has encountered a new vein, thought to be the "back" vein, which is 12 feet in width and in ore content compares favorably with the main vein. Four feet of it averages about $28 to the ton and the rest is good milling ore. The location is on the Causten lower tunnel level, at 800 feet from the portal, and the vein is thought to contain much workable ore below this level and the surface.

Developments in September, 1914, have shown the presence of this vein, with practically the same width and ore tenor as above described, extending through the deep parts of the Big Four and Four J mines, thus indicating a continuous length of 1,000 feet of milling ore on the several leases at depths of 400 to 600 feet.

The Causten or Four J lease, about 1,000 feet north of the Codd lease, is opened mainly by a lower tunnel, the Causten or main crosscut tunnel, which is 300 feet lower than the collar of the Codd shaft, and by an upper tunnel 300 feet above the lower one. At the time of visit the upper tunnel, 265 feet in length, connected with 120 feet of drift and had yielded some $6 ore.

The lower tunnel at that time had a length of nearly 200 feet. It penetrated altered decomposed brownish iron-stained blocky rhyolite, less siliceous than the average rock in Nenzel Hill. Some of the less oxidized rock near the face contains pyrite finely disseminated. The tunnel driven to the east follows a zone of crushed, altered, and silicified rhyolite and rhyolite breccia 18 inches wide which in places gave assays of more than $300 to the ton, but, as in the upper tunnel, the average material is not of shipping grade. Several tons of it lay sacked on the dump. In some of this ore 10 per cent of the value is said to be in gold. The country rock is cut by joints into cuboidal blocks 2 to 3 feet across.

By December 1, 1913, the tunnel had been extended to a length of a thousand feet, giving a depth of about 400 feet on the main vein, and a body of $16 ore had been cut. In January, after further sinking in the bottom of the Codd mine and drifting in the Causten ground, a new ore shoot 3 to 4 feet wide was reported. The ore in this shoot is said to resemble that of the Colligan lease on the Weaver ground, on the southern slope of Nenzel Hill, and to average about $100 to the ton, with two-thirds of its value in gold. This ore body, it may be observed, is apparently at the same elevation as the ore of the Colligan workings and is probably at about the same geologic horizon.

Recently it has been reported that workings from this tunnel have been extended to the depth of 520 feet, the greatest yet attained in the district, and that the vein, which continues about 8 feet in width to this depth, consists chiefly of milling ore, of which by June the mine had blocked out and accumulated 20,000 tons. There are, however, some bodies of richer ore from which the Four J lessees began shipping early in March. Subsequently, in an upraise from the main level, a shoot of $30 ore 2½ feet wide was encountered, which is thought to be a continuation of the shoot exposed in the north end of the Codd lease.

The operators of the No. 4 lease, which lies between the Codd and the Causten leases, ship from time to time a carload of $30 ore from relatively shallow workings. About a thousand feet north of these, the lessees of Block 8, on the Crown Point No. 3 claim, opened by shaft and tunnel in the northeast slope of Nenzel Hill at 7,000 feet elevation, are also working in good ore. The Camille Rock lessees, also on the Crown Point Mining Co.'s ground, near by, are reported (April, 1914) to be working a 6-foot vein of ore, mostly of shipping grade, which has been stripped on the surface and shows well for a distance of 400 feet. At the depth of 65 feet the vein contains a body of gold-silver ore 6 feet in width, which assays from $40 to $80 to the ton.

The ore minerals in the deposits of Nenzel Hill occur chiefly in quartz that has replaced rhyolite and are sporadically distributed through this in small aggregates, much of the ore having a blotchy or mottled appearance. To some extent they occur in the vugs, and secondarily they follow lamination or fractures in the quartz.

The silver-bearing minerals, which are the important constituent of the ores, owing to their fine-grained aggregation, are not easily determined. In much of the ore bindheimite, a yellowish-green mineral consisting chiefly of hydrous lead antimonate and resulting from the decomposition of other antimonial ores, is common. From this occurrence it appears that silver-bearing sulphantimonites may be present. Among the minerals Jones[1] has recognized pyrargyrite. Argentite, which is regarded by Mr. E. B. Mills, superintendent of the Rochester Mining Co., as probably the principal ore mineral, seems to be present generally, accompanied in places by a little proustite. Scales of native silver are visible here and there, and rarely, with the pocket lens, a few specks of free native gold may be seen. The Big Four and Codd ore averages one four-hundredth of an ounce, or about 5¼ cents in gold to the ton, but the gold is said to increase with depth. Other silver minerals reported by mining men are cerargyrite and bromyrite. At the time of the writer's visit the ore minerals could be more satisfactorily studied in material from the No. 4 shaft on the Crown Point No. 1 and in neighboring small openings in the northeast slope of Nenzel Hill than in that from the larger workings.

The ore, according to smelter returns, contains about 93 per cent silica. Besides quartz and the minerals just mentioned it contains some pyrite, a little chalcopyrite, and in places a very little sphalerite and galena. The ore is commonly stained pale brown by oxidation products, particularly by limonite and hematite derived from the pyrite. In places it is stained green or bluish by malachite and azurite derived from the chalcopyrite. In some places these copper carbonates line vugs and appear to be of recent deposition.

In the southern part of the Nenzel Hill area, on the south slope of Nenzel Hill, the Rochester-Weaver Mining Co.'s ground has been opened by about 4,000 feet of work, including a 430-foot adit. The principal openings are on the Colligan and Shea lease blocks. The ore bodies have been found to extend to the depth of 350 feet. At that depth three veins have been crosscut.

At the Colligan lease, worked by the Rochester Nugget Mines Co., the country rock is a purplish-brown porphyritic rhyolite, considerably altered and traversed by veinlets of sericite. The strike of the vein, N. 17° E., is intermediate between that of the northward trending system and that of the north-northeastward trending system. It is probably a continuation of the West vein, although its connection with that vein has not been established. It is in general nearly vertical, dipping here to the west and there to the east. It ranges from 1 foot to 3½ feet in width.

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[1] Jones, J. C., loc. cit.

The vein is composed of brownish or yellowish fine-grained quartz and silicified rhyolite, the color being due to limonite. Most of the ore is soft and pulverulent, but the vein contains also some harder ore, like that of the Codd and Platt mines. At the time of the writer's visit the workings comprised a 55-foot crosscut tunnel, 90 feet of drift, and a 16-foot winze. The mine had produced 90 tons of $27 ore, of which 40 per cent of the value was in gold and the remainder in silver. According to returns of the Mason Valley Mines Co.'s smelter, the ore contains also 13 per cent of iron.

By December, 1913, the Colligan mine had attained a depth of 210 feet and the lessees had shipped 320 tons of ore, which averaged nearly $42 to the ton. More than one-third of the value of this ore was in gold. In May much of the ore was reported to average $75 to the ton.

On the neighboring Gillespie or Shea-Kelleher lease, about 1,000 feet east of the Colligan, is an incline shaft, 600 feet deep, on what appears to be a 16-foot lode, which is parallel to that of the Colligan. The workings are on the southwest slope of Nenzel Hill, in brown rhyolite. Later reports indicate that the mine contains an ore shoot 4½ feet wide, which averages about $50 to the ton in gold and silver. Prior to December 1 the mine had produced over 170 tons of ore, which averaged approximately $26 to the ton. At the time of the writer's visit about 6 tons of good-looking quartz ore lay on the dump. The ore contains some pyrite. In August the mine was reported to have blocked out over 10,000 tons of ore ready for stoping.

Operators of neighboring leases, the Cole, Friedman, and Case, also on the Weaver ground, on the south slope of the hill, have made small shipments. Late in March, 1914, it was reported that a shoot of $100 ore, 18 inches wide, in which the value is chiefly in gold, was struck on the Cole lease, at a depth of 125 feet. A carload shipped in May is said to have yielded returns of $142 to the ton in gold.

The East vein or ledge outcrops along the upper east slope of Nenzel Hill, lying approximately parallel with the West vein, from which it is 1,200 to 1,400 feet distant. It has a known length of about 1,000 feet, mainly within the January Fraction claim, but it extends for a few hundred feet into the Crown Point No. 1 claim, to the north. The lode shows rugged croppings of silicified rhyolite, which dip 75° W. into the hill and toward the east form a steep scarp about 100 feet high.

The lode is opened at several places. The most important opening is at the north end, in the Roy Ridge mine. At this place 8 tons of ore, said to average $100 in silver and $1.50 in gold to the ton, was taken from a 50-foot shaft. The lode is from 3 to 5 feet wide. Both the vein and the wall rock contain disseminated pyrite and a very little pyrrhotite.

The Nenzel Hill ore deposits, if they persist downward, as appears probable, are admirably situated for working through crosscut tunnels, which, driven from the east or west side of the hill, would give from 600 to 1,000 feet of depth, according to the location of the tunnel.

In the adjacent part of Sunflower Ridge, which incloses Rochester Canyon on the south, and in the saddle separating this ridge from the south end of Nenzel Hill, several veins have been opened on the Sunflower group of claims, owned by the Rochester Belmont Mines Co. Here the Sunflower vein, opened at the time of visit by a 50-foot shaft south of the saddle, has a width of 10 feet and dips steeply to the east in rhyolite. At present (May, 1914) a lease being operated in the saddle is said to be producing good ore, and from one of the openings pockets of very rich surface ore, averaging 27 ounces in gold and 362 ounces in silver to the ton, are reported to have been taken.

The Hockley-Boughton lease, almost adjoining the Sunflower property on the west, is also said to be shipping good ore, a carload of which averaged $87 to the ton.

The Limerick gold mine is opposite the Sunflower on the upper south slope of the ridge that bounds Rochester Canyon on the north. It is located on patented ground, which extends across the ridge and lies in part on the Limerick Canyon side. It is owned by C. N. Miller, of Fairport, Cal. The country rock is rhyolite, which is stained with limonite and locally has a honeycombed structure. In general the rock is so crushed, sericitized, and otherwise altered that there is scarcely anything for the prospector to follow. A sheeted structure dips 25° W., and silicified croppings one-eighth of a mile up the slope dip 60° W.

The mine is opened mainly by a 90-foot incline of 15°, which extends N. 20° W. along two or more ore-bearing layers of breccia composed of quartz and rhyolite. The layers in general dip west, but are very irregular. The gold is sporadically distributed in very fine particles. Cerargyrite is sparingly present, and proustite is reported. At the time of the writer's visit a small consignment of $125 ore had been shipped, and about 5 tons were sacked on the dump.

A moderate amount of sinking and systematic east-west crosscutting at right angles to the well-known dominant structure and vein systems of the district would be likely to show whether the property contains any well-developed ledge or extensive workable deposits.

The Plainview mine is nearly a mile north of the Limerick and a half mile south of Panama, in the open head of Limerick Canyon, at about 6,300 feet above sea level. It lies in altered, silicified, and very highly sericitized gray rhyolite and is opened by considerable work extending for some distance below and above the ore road of the Rochester mines.

The lower tunnel, 500 feet long, runs N. 55° E. on an irregular shear zone or fault plane, which dips 60° NW. The rock is crushed and partly silicified, iron-stained rhyolite, considerable portions of which for a few feet in width are said to average about $9 to the ton, chiefly in gold, some of which is visible in the rock. The deposits, however, are apparently too low in grade to be workable under present conditions.

About half a mile northeast of the Plainview mine, on the west side of the pass between Limerick and American canyons and at about 6,400 feet above sea level, are strong croppings on what is known as the Orms prospect. These croppings show altered rhyolite, or perhaps dacite, for besides much quartz the rock contains considerable lime-soda feldspar, and some chlorite after biotite.

The ledge, from 3 to 8 feet in width, strikes approximately east and west and is opened mainly by a 100-foot tunnel drift. It is composed of silicified rock, closely banded by veins and stringers of quartz, and shows considerable free gold, but the ledge at the time of the writer's visit appeared to be irregular and difficult to follow.

Just over the ridge from the Orms prospect, on the southeast slope of the pass between Limerick and American canyons, are some deposits that differ from those of the Nenzel Hill class in that they are more distinctly of vein character, without the replacement features which are so characteristic in Nenzel Hill. The country rock is rhyolite or quartz latite porphyry, resembling that at the Orms prospect. It occurs in heavy sheets or flows, dipping 50° E. A portion of the rock which crops in a rather prominent reef several feet in width appears to be a later intrusive sheet or dike.

The deposits consist of a series of approximately parallel quartz stringers and veins, which also dip 50° E. in approximate conformity with the porphyry. They range from a few inches to 2½ feet in width. From croppings and prospects in the northeast slope of the hill it is estimated that one or more of the veins has a vertical range of at least 200 feet. The metallic minerals conspicuous in the veins and stringers are sphalerite, galena, and pyrite, all more or less intermingled. They occur crudely banded or as streaks and are not present in workable quantity. The metal for which the deposits are being exploited is said to be silver, the silver-bearing minerals being apparently associated with the galena and only sparingly present.

SOURCE OF THE NENZEL HILL ORE DEPOSITS.

The Nenzel Hill ore deposits, as shown by the quartz phenocrysts which they contain, and by their outward transition from nearly pure quartz into rhyolite, were formed by replacement of that rock, already rich in silica. Although the contact between the veins or ore zones and the wall rock is in general well defined, its undulatory, irregular character is also indicative of replacement.

The deposits have supposedly been formed by ascending hydrothermal solutions derived from some intrusive magma. This magma may have been that corresponding to one of the volcanic rocks or that of some underlying granite, possibly a southerly extension of the granite mass of Rocky Canyon.

The heated solutions probably continued to ascend long after the intrusion of the magma. The water of Black Knob Spring, near Packard, is slightly warm, and in American Canyon the rocks in a 200-foot shaft are reported to be above the usual temperature for rock at that depth. But the heat in these places is likely to be due to later processes than those connected with the origin of the ore deposits.

In a few places on the south slope of Nenzel Hill structures were observed that suggested the pseudomorphic replacement of calcite by silica, but the evidence was too indefinite to justify the conclusion that silica has extensively replaced a calcite gangue as it has in some districts in Nevada and Arizona.

The irregularity in the lateral extent of silicification, considered in connection with the greater abundance of primary quartz phenocrysts in the less silicified portions of the deposits as compared with the more silicified, indicates, as urged by Whyttock,[1] that silicification and ore deposition were most active in the more feldspathic portions of the rocks, the feldspar being particularly susceptible to metasomatic replacement.

PACKARD ORE DEPOSITS.

The Packard ore deposits resemble in some respects the Nenzel Hill deposits, but differ markedly from them in being less well defined and less silicified. They occur in Packard Ridge, a broad, gently sloping spur at the south end of the Nenzel Hill belt, at an elevation of about 5,850 feet. A cross section of the hill is shown in figure 91 (p. 343).

At the time of the writer's visit the ground had been opened in four contiguous claims, known as the Packard group (Pl. VIII). The first location here was made in December, 1912, by Henry Lund.

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[1] Whyttock, P. R., oral communication on the ground; see also Min. Rev., vol. 15, No. 2, p. 21, Apr. 30, 1913.

The rich silver ore now being worked was found by R. Ray in the following May, and soon thereafter the property was sold for $5,000 to the Rochester-Packard Mines Co., which at once began operations, and late in May was shipping ore.

Along the crest of the ridge a belt of craggy silicified rhyolite, 100 feet wide, commonly known as the "dike," indicated by C in figure 91, rises about 12 feet above the surface. The croppings are sheeted like the adjoining rhyolite, of which they appear to be only a silicified part. They are also traversed longitudinally by some vertical, slickensided surfaces, and the "dike" apparently is a silicified fault zone.

In a few places, where the rock has not been rendered schistose, it appears fresh and resembles Tertiary rhyolite, but under the microscope it is found to be devitrified, silicified, and sericitized.

The ore deposits, as shown in figure 90 (p. 335), occur on both sides of the fault zone and are generally parallel to it in strike though not in dip. They conform to the general layering and schistosity of the rhyolite, the ore bodies on the southeast side of the fault zone dipping toward that feature, whereas those on the northwest side dip away from it. Very little ore occurs in the fault zone itself.

The croppings of the ore deposits, unlike those of the fault zone, are not prominent and in some places are slightly lower than the general surface. They consist mainly of mineralized schistose rhyolite, which generally constitutes shipping ore from the surface down. The widespread occurrence of ore at the surface has led many to believe that the deposits as a whole represent a great blanket vein.

The best exposure of the deposits at the time of the writer's visit was on the Packard No. 2 claim and on the Packard Fraction adjoining it on the west. At this locality, 150 feet west of the silicified fault zone, the deposits occupy the greater part of a belt about 30 feet wide, whose known length is about 1,200 feet. This zone is marked "O" in figure 90 (p. 335).

In places the ore had been stripped by plow and scraper and was being worked in several openings from 1 to 8 feet in depth. From one of the main pits, about 10 feet in diameter by 8 feet in depth, a carload of ore had been shipped which averaged $61 to the ton—about $58 in silver and $3 in gold.

Work was being done in 8 or 10 similar shallow openings on the Jackson, Cold Storage, Enterprise, and other ground on the east slope of the ridge, where the deposits extend interruptedly from the vicinity of the fault nearly to the base of the ridge.

The ore minerals appear to be chiefly cerargyrite and argentite. They occur in the schistose and partly silicified and replaced rhyolite.

Much of the ore is a schist with a silvery sheen, and its general appearance gives little suggestion of its value. In some varieties, however, purple or reddish-gray iron-stained quartz is present locally in bodies or lenses several or more inches in width, which, however, are irregular and ill defined and in part at least have been deposited by replacement.

Some siliceous portions of the ore are speckled and in places honeycombed by cavities from which pyrite has weathered out and which are now occupied in part by hematite and limonite. In some places silver appears to occur in these cavities, associated with the iron. Small faults and sharp buckling of the rhyolites against the quartz, which is also shattered, show that considerable movement took place after the quartz was deposited.

The Packard ore deposits unquestionably have a genetic connection with the fault zone. They were probably derived from siliceous hydrothermal magmatic solutions, which, in ascending the fault fissure shown at F–F′ in figure 90 (p. 335), deposited the quartz and ore minerals by metasomatic replacement in certain layers or portions of the rhyolite. The rock replaced, as in Nenzel Hill, was probably less siliceous and more feldspathic than the present country rock. This selective action apparently explains why ore minerals are only very sparingly present in the silicified fault zone itself.

As the fissure, which is nearly vertical, cuts the inclined formations obliquely, the deposits in the beds to the east or right of the fault, as shown in figure 90 (p. 335), were deposited by solutions which on leaving the main fissure ascended, whereas those to the west or left were deposited by solutions which on leaving the fissure descended, as indicated by the curved arrow at T in figure 90. When ore deposition took place the rocks, as indicated in the figure, extended far above the present surface of the ridge, to which they have since been reduced by erosion. This erosion has shifted the outcrop of the ore zone (O in fig. 90) to a distance of 150 feet from the fault, from which it is now separated by a belt of barren rock. The deposits to the right or east of the fault may be expected in general to connect with the fault fissure in depth, and below any enrichment by oxidation that may have taken place from the surface they should show increase rather than diminution in tenor with depth and with nearness of approach to their source. With some offsets due to movement along the main fault zone these ore deposits east of the fault probably continue to depth beyond the fault (F–F′ in fig. 90), but until the amount of throw is determined their exact positions must remain unknown.

On the other hand, the deposits to the left or west of the fault, which are now the main source of the camp's production, do not, if the explanation of their origin is correct, hold out much promise of great downward persistence. The ore now being mined here is apparently the result of surface enrichment in the oxidized zone and represents in large measure a concentration from portions of the deposits now eroded away. (See fig. 90.) The continuation of this relatively high-grade ore to great depths is not to be expected.

It is possible that deeper ore zones that do not outcrop may occur between the ore zone (O) now being worked and the fault. This could be determined by sinking and crosscutting on the west of the fault, preferably from the bottom of fairly deep workings in the ore zone. Strong probability that the down-thrown portions of the ore beds east of the fault may be found here lends encouragement and purpose to the undertaking.

A quartz vein 2½ feet wide, on the north end of Packard No. 2 claim, occupies a well-defined fissure in the rhyolite. The vein strikes N. 25° W. and dips 80° SW. It is composed of vitreous quartz, which carries only a little gold and practically no silver. Its course is nearly at right angles to the trend of the main deposits of the camp, with which it apparently has no connection. On the dump were seen a few crystals of smoky quartz an inch and a half in diameter, some with perfect pyramidal termination, which appear to have come from the vein.

In October, 1913, the operators of the Packard property were reported to have opened a 3-foot vein of rich silver ore, some of it running as high as $400 to the ton. The exact location of this vein has not been learned.

During the winter and spring press notices of development reported continued work on the deposits here described and the discovery of new ones containing bodies of both shipping and milling ore.

Late in April, 1914, a new 11 to 20 foot vein, mostly of $25 ore, was reported to have been discovered about 200 feet down the slope to the west or hanging-wall side of the main ore zone. (See O in fig. 90.) As its dip is steeper than that of the main ore zone, to which its strike is also oblique, it should join or intersect that zone at no great depth. On the first level it is said to contain about 8 feet of good milling ore and 3 feet of high-grade shipping ore, which averages about $60 to the ton. The ore is described as composed mainly of stringers and druses containing much horn silver. Associated with slips, which are said to be common in the vein, the miners report considerable "talc" or gouge, which averages about $21.50 to the ton in silver.

Late in May another vein or ore zone, 75 feet wide, is reported to have been discovered, from which a carload of $100 ore was shipped, and some specimens, each weighing several pounds, averaged 3,000 ounces in silver to the ton. In September it was reported that the lower workings, on what is probably an extension of this zone, have opened a body of milling ore approximately 100 feet wide, 20 feet thick, and 65 feet or more long, the developments in the last-named direction still being in ore. This body also contains a few ore shoots of shipping grade. One shoot 8 feet in width is said to average about $120 in silver and $11 in gold to the ton.

In July and August the Kromer-Hampton lease, which is on Packard ground, was said to be shipping about 100 tons a month of ore averaging about $70 to the ton, and the Nevada-Packard Co. 3 to 4 carloads a month of ore averaging about $65 to the ton. The company is said to have decided to build a mill to treat the ore by amalgamation and cyanidation.

With the completion of the railroad into the district shipments of Packard ore will be greatly increased. Much of the ore produced in this area still comes from open-day workings.

LINCOLN HILL BELT.

GENERAL FEATURES.

The Lincoln Hill belt, as shown by the distribution of the claims in the western part of the area (Pl. VIII), extends from Weaver Canyon northward across Rochester and Limerick canyons and apparently also across the crest of the range into Spring Valley, on the north.

Here the newly described deposits, which early in 1913 attracted much attention and determined the location of Lower Town, occur mainly in Lincoln Hill, where at the time of the writer's visit there were several producing properties from which shipments of high-grade ore had been made, and where some very rich ore continues to be found from time to time.

LINCOLN HILL DEPOSITS.

Lincoln Hill is an elongated oval mass about a mile long and three-fourths of a mile wide, rising to an elevation above sea level of 6,600 feet, or about 1,200 feet above Rochester Canyon, which adjoins it on the south. It is separated on the north from Gold Ridge, of Oro Fino fame, by High Grade Canyon. It is composed chiefly of rhyolitic rocks in which the dominant structure is a pronounced sheeting accompanied by shearing and schistosity. These structures strike N. 30° W. and dip 40° WSW. A second sheeting, which in strike approximately parallels the hill, dips 65° NW.

In the rhyolite are numerous quartz veins and stringers, which are the source of the rich float found on all sides of the hill and which during the boom occasioned the staking of nearly 100 claims. They comprise mainly two sets. The more important one follows approximately the strike of the northeast-southwest sheeting and apparently corresponds to the main vein system in Nenzel Hill. The other set, at about right angles to the first set, strikes approximately northwest and forms an angle of about 25° with the N. 30° W. sheeting. To this set apparently belongs also the vein of the Oro Fino mine, a mile northwest of Lincoln Hill.

The Lincoln Hill veins are smaller than the Nenzel Hill veins and more nearly resemble veins of the filled-fissure type. They contain tourmaline, specularite, and other minerals in quartz, and the valuable metal is almost entirely gold. Bromyrite has been found by Mr. J. Phelps at the south base of the hill.

The deposits occur chiefly in six or eight veins on the west slope of the hill. The principal openings on them are the Summit and Supreme mines on the northwestward-striking system and the Forvilly mine on the northeast-southwest system.

On the latter system, on the Abe Lincoln No. 2 claim, at an elevation of 6,400 feet, the Forvilly mine, owned by Messrs. Campbell and Forvilly, is opened mainly by two 40-foot shafts, one on each of two veins which lie about 20 feet apart and dip 80° NW. Here the southeast vein is 3 feet in width and the northwest one is wider. Stoping is done on both veins to the northeast of the shafts. The walls are good but generally "frozen" and without gouge. The veins are composed mainly of quartz, in small part replacing rhyolite, and of altered and silicified rhyolite. In places they are vuggy or porous.

The ore in places is crudely branded. Its contents in gold and silver are approximately equal in value. With it is associated some finely disseminated pyrite. About 120 tons of ore, averaging about $58 to the ton, had been shipped at the time of the writer's visit, and 5 tons were sacked or piled on the dump.

The Summit or upper Forvilly mine, about 700 feet east of the mine just described, is in a saddle in the crest of Lincoln Hill at an elevation of 6,450 feet. Its vein, which belongs to the northwest-southeast system, is 2½ feet or more in width and dips 60° NW. It is opened by an incline shaft. The country rock is rhyolite. The ore, of which several tons were lying sacked on the dump at the time of the writer's visit, is apparently of good grade and shows much free gold. It resembles the ore of the Supreme mine, next to be described, which, together with the fact that it is approximately on the projected course of the Supreme vein, suggests that the deposits at the two mines may be on the same vein.

In September, 1914, development of the Forvilly mines is reported to have continued with gratifying results, gold, mostly free milling, being found plentifully throughout the deposits. A stamp mill is said to be treating the ore on the property since October 15.

At the Supreme mine, operated by W. N. Harwood and associates, which is located about 1,600 feet west-northwest of the Summit mine, at an elevation of 6,100 feet, the deposits occur in an 18-inch vein that dips 80° NNE. in rhyolite. The vein is composed mainly of a pale-brown iron-stained gangue of quartz, which has replaced rhyolite, and of silicified rhyolite. The croppings extend along the slope for several hundred feet and in the adjacent wall of High Grade Canyon are exposed for a vertical distance of over 100 feet.

The vein when visited had been opened horizontally for 40 feet and to the depth of 30 feet. It apparently consists mainly of completely silicified rhyolite or quartz. The walls, though well defined, are tight or frozen and without gangue, conditions which are not promising for continuity. The ore shows much free gold in wire and other forms. In some specimens the jagged wirelike forms protrude a twentieth of an inch above the surface of the weathered quartz. The gold is noticeably abundant in the quartz within half an inch of the less completely silicified rhyolite and in the darker varieties of the quartz. In places the vein for its full width is said to average $1,500 to the ton, and picked samples are said to range from $3,000 to $5,000 to the ton.

Associated with the ore in places are pyrite and a little specularite in crystals about a fifth of an inch in diameter. A 5-ton test shipment is reported to have averaged $187 in gold and 12 ounces in silver to the ton. In places in the vein occur small stringers or lenses of apparently later milky-white quartz, with a few fresh feldspars. In these, however, no gold was found.

Down the slope to the south, about 50 feet from the Supreme vein, is a similar vein, and 1,500 feet to the west-southwest, on the New Prince ground, are three parallel stringers or veins, of similar character, from 12 to 14 inches in width. These veins as yet have received but little development.

Recently (September, 1914) the Blowback claim, adjoining the Supreme mine on the south, is reported to have been worked and to have made a shipment of ore which averaged $250 to the ton, nearly all in gold.

Developments are also showing up well on the Flunky No. 2 claim, near by, which is reported to have just been acquired by the Lincoln Consolidated Co. for $37,500. It will be operated in conjunction with the company's adjoining property, on which also extensive development work is being done.

SOURCE OF THE LINCOLN HILL ORE DEPOSITS.

The Lincoln Hill ore deposits examined in 1913, like those of Nenzel Hill and Packard, appear to have been formed chiefly by hydrothermal solutions, but pneumatolytic action seems also to have played an important part, as is attested by the presence of tourmaline in the veins. The process of formation was more of the nature of fissure filling with less replacement than in the Nenzel Hill deposits.

South of Lincoln Hill, in the north slope of the ridge that bounds Rochester Canyon on the south, the deposits of the Buck and Charley mine, which was not visited, also occur in the rhyolite. They have produced upward of $10,000 worth of ore.

In the lower tunnel of the mine, at a vertical depth of 200 feet, the vein is reported to carry a width of 4 to 15 feet of $18 ore with shoots 1 to 3 feet in width composed chiefly of ore averaging about $125 to the ton, mostly in gold. The mine is favorably situated for shipment, being directly on the line of the Nevada Short Line Railroad, which is now being extended.

In the northern part of the Lincoln Hill belt, in Limerick Canyon, are several prospects which were not visited. Among them is an opening on the Empire ground, on a quartz vein in greenstone. The quartz apparently in part has replaced barite and carries tetrahedrite, a little stibnite, and molybdenite.

Of the earlier workings in the Lincoln Hill belt the Oro Fino and Montezuma deserve passing notice. The Oro Fino mine, which was not visited, is situated about a mile northwest of Lincoln Hill, just across High Grade Canyon, on a southwest spur of Gold Ridge. A series of dumps suggested by their alignment that the vein belongs to the northwest system. It is thought by J. T. Reid to be on the same fissure or contact as the Humboldt Queen mine,[1] near the mouth of Limerick Canyon, described by Ransome. This fissure is held by some mining men to contain other promising prospects higher up in Limerick Canyon.

According to reports, the Oro Fino mine in 1879 produced $58,000 in high-grade gold ore, and in the early eighties it produced about 200 tons of low-grade ore, averaging from $6 to $7 a ton, which was treated in a 5-stamp mill in the lower part of Limerick Canyon. Later Mr. Schmidt, of Ryepatch, is reported to have found in it a pocket of rich ore which yielded about $2,000. By some the mine is thought still to contain considerable workable ground.

The old Montana shaft in Rochester Canyon, about a mile below Lincoln Hill, is on what appears to be a rhyolite dike dipping steeply west in the limestone of the Koipato formation. It is owned in New York. It was sunk in the early sixties and for a time produced some high-grade ore. Since then it has not been productive. According to tests made by P. R. Whyttock,[2] the Montezuma and adjoining ground yield good assays.

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[1] Ransome, F. L., op. cit., p. 33.

[2] Oral communication.

DEPOSITS IN NEIGHBORING LOCALITIES.

The discoveries made in Nenzel Hill and Lincoln Hill in 1912 and 1913 naturally led to considerable prospecting in the surrounding hills, which resulted in a revival of activity at some of the old deposits and the discovery of some new ones.

McILRAVY PROSPECT.

About a mile northwest of Spring Valley Pass, and half a mile outside of the area mapped in Plate VIII, at an elevation of about 6,700 feet, is a deposit that differs from anything heretofore described in this report. It contains copper-silver ore in a barite-quartz gangue, barite having been apparently in part replaced by the quartz. The deposit occurs in the form of a bed, or bed vein, about a foot in width, which dips 25° SW., conformably with the general structure of the country rock, a dark greenstone (diorite porphyry?), and contains layers a few feet thick of a pale-green siliceous rock which is now a sericite-quartz schist but may have been originally rhyolite.

The deposit occurs in or associated with one of these layers. It is opened mainly by a 30-foot incline. The ore minerals are azurite, malachite, chrysocolla, a little chalcopyrite, chalcocite, cerargyrite, and apparently some silver-bearing sulphantimonite. They occur associated, mainly in lenses and kidneys from 2 to 6 inches in width lying parallel with the walls of the vein. They are more or less interbanded or streaked with the barite-quartz gangue, with some dark-greenish micaceous mineral apparently belonging to the chlorite group, and with a dark-greenish mixture composed apparently of oxide of iron and manganese, with a little copper, pitchblende, and epidote. Some chalcopyrite also occurs in the vein. A considerable portion of the ore is said to average from 5 to 6 per cent in copper and $60 in silver to the ton.

Northwest of the McIlravy prospect the greenstone becomes diabasic and extends into the mountains for the distance of a mile or more. It weathers in blocky forms which roughly resemble columnar structure, and for the first half mile or so beyond the McIlravy prospect it contains numerous barite veins from 2 to 10 inches in width, dipping steeply northwest. Associated with the barite in the veins are some chloritic minerals. Some of the barite is coarsely crystalline.

LEE-STUART MINE.

Beyond the McIlravy prospect, at the head of Spring Valley, about a mile and a half north-northwest of Spring Valley Pass, deposits occur on the Lee-Stuart ground, which, at the time of the writer's visit, were attracting attention through a strike made by a lessee named Carpenter.

The deposits comprise three parallel veins or lodes, which are shown by croppings and openings to have a length of about a mile. They dip steeply northwest into the mountain and are spaced about 1,600 feet apart horizontally and 500 feet apart vertically, the lowest vein being at an elevation of about 6,000 feet and easy of access. They are mineralogically similar to the deposits of Lincoln Hill, and apparently form the northward extension of that belt of mineralization.

These deposits lie in the porphyroid rocks of the Koipato formation. The veins are approximately parallel with those of the main Nenzel Hill and Lincoln Hill system and seem to owe their position to the same system of sheeting or fissuring. In size and in their composite or lodelike character, the veins resemble the deposits of Nenzel Hill, though mineralogically they appear to be more like the Lincoln Hill type. The gangue is chiefly quartz with some silicified, altered, and replaced rhyolite or other rock, a portion of which may have been originally dike material. The quartz commonly contains needles and prisms of black tourmaline and rather large scales of specular hematite. The gold is free and coarse.

The lower vein, on which most work has been done, is opened by an 800-foot tunnel, which is driven chiefly through greenstone and crosscuts the vein at about 400 feet in from the portal. Here the vein shows a width of 16 feet. It is composed mainly of a mixture of quartz and rhyolite containing free coarse gold.

Near the southeast end of the vein, about 1,500 feet from the tunnel, are the Gold Dike and two other shallow shafts. The ore here shows considerable coarse free gold. Some particles are a fifth of an inch in diameter.

The gold occurs chiefly in the quartz stringers and in the altered silicified porphyry within the lode, generally at or near the walls of the stringers. It occurs also in streaks of coarsely crystalline hematite that has apparently been derived from pyrite, and to some extent associated with fresh-looking black needles and prisms of tourmaline embedded in the quartz. Some of the hematite is very rich, the gold being contained in that mineral, with which, in places, is associated a little pyrrhotite.

These Lee-Stuart veins apparently contain a large amount of gold, but owing to the sporadic distribution it is doubtful whether they are workable under present conditions. They were an important source of the gold mined in the Spring Valley placers, and they suggest that veins of their class were probably the chief source of the gold found in the American Canyon placers. The ore of the middle vein is said to contain, besides gold, argentite and other sulphides with some copper, and to be in part refractory.

Near their western ends the veins are intersected diagonally by two east-west veins, which also carry some gold. Where they intersect the lower vein, a few hundred feet northeast of the Gold Dike shaft, they are about 80 feet apart and dip steeply north.

Here, as at Lincoln Hill, the presence of tourmaline associated with the gold in the quartz indicates that pneumatolytic processes, as well as hydrothermal action, probably played an important part in the origin of the deposits, and the occurrence of the deposits and associated minerals toward the sides of the veins shows mineralization to have taken place chiefly during the early stages of fissure filling and vein formation. That some of the veins are altered dikes appears probable, but conclusive evidence of this has not been observed.

COLE PROSPECT.

At the time of the writer's visit considerable interest was also manifested in cinnabar prospects in the surrounding region, and several newly discovered deposits were reported from the south end of the Star Peak Range. Most of these deposits are in the altered rhyolitic rocks and are generally similar in their occurrence.

The nearest of the prospects is in South American Canyon, about 1½ miles from Nenzel Hill. In this locality, on the east side of a gulch on the north side of the canyon, the cinnabar deposits are said to occur in three parallel northward-dipping veins in the rhyolite, one of which belongs to G. Cole, of Rochester. The entrance was locked at the time of the writer's visit and the workings were not examined. The deposits appear to be similar to those at the Dixie mine, next to be described, though apparently they are more extensive. The cinnabar, as seen in specimens, occurs as specks and small irregular veinlets, the largest three-tenths of an inch in width, in the altered kaolinized rhyolite. Some of the mineral is well crystallized.

DIXIE MINE.

In American Canyon, about 2 miles northeast of Nenzel Hill and 1½ miles down the canyon, cinnabar has been known for some time at the Dixie mine and Nevada Almaden prospects. These lode deposits were discovered through the finding of particles and pebbles of cinnabar in the gold placers, and recently the United Placer Co. is said to have been organized for the purpose of resuming work on the gravels of American Canyon for cinnabar and gold.

The Dixie mine is owned in Lovelock. Its deposit was described by Ransome[1] as a soft crushed kaolinized zone, at least 6 feet wide, in porphyritic rhyolite, with little specks of cinnabar scattered through the kaolin. The zone, without exposed walls, dips into the hill at 15°-20° N. and is opened by an incline 200 feet long, with considerable drifting.

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[1] Ransome, F. L., op. cit., p. 37.

At the time of the writer's visit the incline had been sunk 200 feet deeper and additional drifts driven from it. Ore has been found all the way down, the cinnabar occurring in specks and small irregular bodies in the kaolinized rock. The ore is treated on the ground in a small mill and retort plant, which, it is said, produces quicksilver on a commercial scale from time to time. The ore is said to average about 2 per cent of metal.[1]

NEVADA ALMADEN PROSPECT.

The Nevada Almaden prospect, owned by W. G. Adamson, of Winnemucca, which was not visited by the writer, is reported to be promising. The ore occurs in limestone with some eruptive rock forming the hanging wall. The vein is said to strike northwest and to dip 20° SW. Specimens shown to Mr. Ransome by Mr. Adamson "contained abundant cinnabar in small irregular fissures in dark-gray limestone. The vein is said to have been traced for a length of 3,500 feet and to have been opened to a maximum depth of 150 feet."[2]

BUTTE PROSPECT.

A cinnabar deposit, reported to be rich, was found in 1913 at Antelope Springs, about 8 miles south of Rochester, at the south end of the Star Peak Range. It is said to be just south of a low basalt-capped foothill butte. Like the neighboring Relief mine described further on, it is most easily reached from Lovelocks, about 18 miles to the west. It is said to occur in rhyolite in small bodies or irregular veinlets and stringers as at the Cole prospect and the Dixie mine, near the contact of the rhyolite with limestone and to extend for 300 yards in a north-south direction.

McNICKLE PROSPECT.

Another cinnabar deposit has been found about 4 miles south of Rochester, a mile south of the McNickle camp, at the west base of the range. It also occurs in altered rhyolite.

All but one of the cinnabar deposits here described, in the southern end of the range, lie in a relatively narrow northeast-southwest belt, which for 9 miles follows the contact of the Koipato and Star Peak formations. The deposits apparently are all in the Star Peak formation. Whether they have any genetic connection with this contact could not be determined in the brief time allotted to this work.

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[1] McCaskey, H. D., Quicksilver: U. S. Geol. Survey Mineral Resources, 1909, pt. 1, pp. 554-555, 1910.

[2] Ransome, F. L., loc. cit.

It is worth noting that cinnabar is absent, so far as known, from the rocks of the Koipato formation, although in the Rochester district deposits in those rocks contain pyrite, chalcopyrite, barite, opal, and antimonial compounds, with which cinnabar is known to be elsewhere associated. The occurrence of the deposits in the Humboldt Range appears to be similar to that of the deposit near Ione, on the west side of the Shoshone Range, described by McCaskey,[1] where also the cinnabar occurs in rhyolite along one side only of a fault contact.

RELIEF MINE.

At the Relief mine, better known as the Old Relief mine, 4 miles south of Nenzel Hill, in the southern end of the range, the ore deposits differ from anything thus far described in the Rochester district in that they occur in limestone and appear to belong to the general class of deposits that occur in the Star Peak Range and are described on page 338.

The deposit was discovered in the early sixties and was worked mainly in the seventies. Current estimates of its production range from $200,000 to $2,500,000. Much of the ore produced was very rich and contained chiefly silver chloride with some bromide, and considerable native silver, some of which formed fine specimens. It apparently contained argentite also. According to J. T. Reid,[2] a carload of the ore shipped to Swansea, Wales, yielded $22,000.

Afterward the mine was worked by the old Rochester Co., and still later by Bailey, who for a time took out much rich ore with large profits. Part of the ore was treated, by pan amalgamation, in a 10-stamp mill built by the Rochester Co. near the mouth of Relief Canyon. This mill was removed in 1874.

From 1898 to 1905 the mine was owned and worked by Mr. Hardesty, of Lovelocks, with fair results. It is now owned and operated by the Rochester Treasure Mining Co. (Inc.), of Lovelocks.

The mine is near the head of Relief Canyon, which heads south of Buffalo Peak and opens southeastward into Black Knob Valley. It lies at an elevation of about 7,000 feet and is accessible by wagon road.

The deposit is a quartz vein or lode, from 15 to 30 feet wide, in limestone. It dips about 55° W., though the limestone dips 40° SW. The limestone is dark gray, in thin to moderately thick beds, partly slaty, and has a thickness of 600 feet or more. It is underlain by light-colored rhyolite, with which it seems to be conformable, and is overlain by a great thickness of dark-greenish, partly schistose andesite, which appears to extend from the vicinity of the mine to the mouth of the canyon, 2 miles distant. The rhyolite is dense and consists chiefly of a microfelsitic to glassy base in which are a few small squeezed phenocrysts of quartz microcline and microperthite.

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[1] McCaskey, H. D., Quicksilver: U. S. Geol. Survey Mineral Resources, 1911, pt. 1, p. 908, 1912.

[2] Oral communication.

These rocks all belong to the Star Peak formation. The contact of the limestone with the rhyolite is about 200 feet from the mine on the north, but no rhyolite has been cut in the workings. In the vicinity of the vein the limestone is in part silicified.

The deposit is opened chiefly by tunnels and drifts for a horizontal distance of nearly 1,000 feet and through a vertical range of about 320 feet. Croppings of quartz that has replaced calcite veinlets and limestone occur also 80 feet above the highest workings.

According to report and observation, the vein is strong at nearly all places where it has been exposed, but the ore occurs mainly as pockets or disconnected bodies ranging in value from a thousand to several thousand dollars. The rich ore is said to be mostly on the hanging-wall side of the vein and that formerly stoped came mainly from the upper and middle levels.

Work is now being done on the 200-foot or Blacksmith Shop level, which is at an elevation of about 7,000 feet and comprises several hundred feet of drifts. Access is gained to it through a 280-foot tunnel, which crosscuts the limestone and at a point 250 feet from the portal reaches the vein. At this place the vein is large and contains, besides stringers of quartz, considerable calcite and layers of limestone, all dipping 60° NW. The calcite and the limestone seem to be in part replaced by the quartz, which was introduced in solution with the ore minerals. The quartz in general is banded and contains some small vugs lined with druses of crystalline quartz. These vugs do not contain ore. A winze is being sunk on the ore body from this level.

On a level about 100 feet lower, consisting of a 375-foot crosscut tunnel and a 30-foot drift on the vein, only gougelike material, some of it said to assay from $6 to $8 a ton, was found.

The upper or 100-foot level, which is about 150 feet above the second level, is opened mainly by a 200-foot tunnel on the vein. The vein, for some distance from the portal, is 3 feet wide and consists of mottled ore. It carries on its hanging wall 6 inches of what appears to be reddish gouge. Farther in, however, this soft material becomes good ore, 2½ feet in width, and the ore body has here been stoped to a width of at least 5½ feet. Much of the high-grade ore extracted in early days came from this level.

About 60 feet above the first or 100-foot level is a large open or daylight stope, which shows that the main part of the lode consists, for a width of 14 feet, of yellowish-brown crushed quartz, next to which, on the hanging-wall side, is 16 feet of rather siliceous mineralized material, including some limestone, all more or less banded and dipping about 50° SSW. The deposit here contains also some crushed material suggestive of altered igneous rock.

Although the quantity and character of ore in the lower workings, so far as learned, are not encouraging for deeper work, the mine apparently still contains considerable ore. It is also held by some that the old dumps, some of which are large, can be profitably milled.

On the opposite side of Relief Canyon, about half a mile south of the Relief mine, and at a slightly lower elevation, is the Silver King mine, which was not visited. Its vein, in limestone, dips northwest and has been opened to a depth of 60 feet. It consists mainly of quartz and manganese oxide, roughly in the proportion of 2 to 1, and contains considerable ore, much of which ranges in tenor from $120 to $1,800 in silver and carries about a dollar in gold to the ton. The ore minerals are said to be chiefly silver bromide and chloride, with the bromide predominant. This property is also being worked on a small scale and is producing some ore.

DEPOSITS IN POLE CANYON.

At Pole Canyon, 6 miles northwest of Rochester and 5 miles northeast of Nixon, discoveries of ore were made at about the same time as at Rochester.

At the time of the writer's visit 18 miners were working in the camp, and 16 tons of ore had been taken out, averaging about $175 to the ton. The ore came mostly from the Hunter, D'Armond, and Lowry leases. Some of it is very rich. The principal metals contained in the ore are gold, silver, and lead.

The deposits occur at an elevation of about 6,000 feet, on the broad steep ridge that forms the south side of Pole Canyon. The topography is rugged and the canyon is deep, affording good exposures of the rocks. From the camp at the head of the wagon road in the canyon, at 5,200 feet elevation, the workings, half a mile distant, are reached by trail. A stream of good water flows through the canyon.

The country rocks are rhyolite and dacite, belonging to the volcanic complex of the Koipato formation, which apparently is represented chiefly by the rhyolitic rocks eastward to the crest of the range.

A few hundred feet west of the deposits the rhyolite is overlain, with steep dip to the west, by quartzite and this by medium to heavy bedded limestone, both apparently belonging to the Koipato formation. A few hundred feet farther down the slope this limestone is overlain by a black limestone, 200 feet thick, belonging to the Star Peak formation, which in turn passes beneath a series of alternating gray and brown beds. As their dip decreases these beds pass beneath the Quaternary sediments of Lake Lahontan.

The country rock of the deposits is porphyritic and some of it shows flow banding. It is traversed by a pronounced north-south sheeting, which has a steep dip to the west, and by numerous joints belonging to other systems. In consequence of these the rock readily separates into small fragments, many of which are less than an inch across. In places the rock is also profoundly sheared and has been rendered schistose, especially near veins and fault planes.

On the north the rhyolitic rocks and the deposits are cut off, as shown in figure 92, by a dark greenstone schist, which appears to have been originally an intrusive igneous rock. The contact dips deeply to the southeast into the mountain. Dark, much crushed and sheared gougelike material, apparently derived from this rock, occurs locally on either wall of the adjoining veins.

The deposits are valuable chiefly for gold and silver, but carry some lead. They comprise three approximately parallel veins, from 200 to 500 feet apart, in the rhyolite (fig. 92). They strike about N. 10° W. and dip 70° E. into the mountain, though in places the dip appears to decrease downward. They have a known length of 3,000 feet or more, and their outcrops show a vertical range of about 100 feet. They are well situated for working by a single crosscut tunnel.

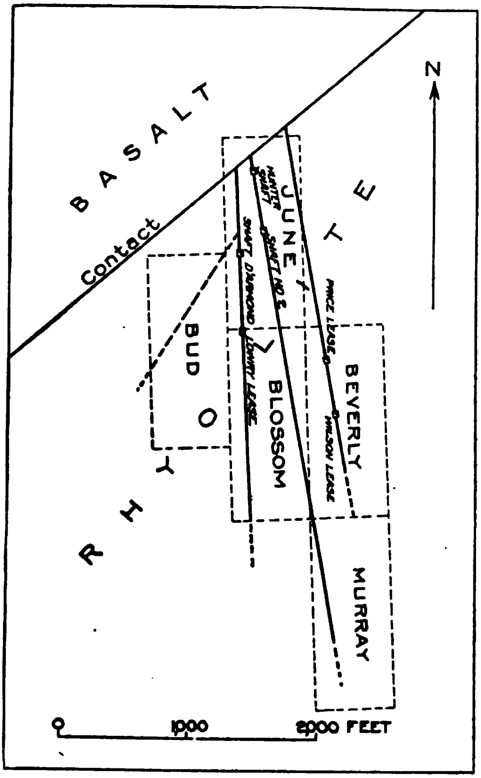

FIGURE 92.—Plan and geologic relations of the principal veins in the Pole Canyon district, Nev.

The veins range in width from a foot to 6 feet or more. The gangue is chiefly quartz, which not only has filled the original fissure, but has replaced the adjoining country rock for distances as great as 40 feet or more from the vein in some places. The veins and rock as a rule are hard and tight, but the vein is not "frozen" to its walls. A distinct parting, in places hardly visible, separates the vein from the wall rock.

The quartz in general is glassy. In part, it shows dark streaks of ore minerals and of partly replaced rhyolite. It contains many small cavities, in some of which free gold occurs, generally in close association with larger masses, apparently, of silver sulphide. The cavities, however, are not generally lined with secondary minerals, although fracture surfaces in the quartz are coated with pearly opaline silica, some of which is colored by iridescent hematite.

The ore minerals are chiefly free native gold alloyed with some silver, pyrargyrite or some dark-reddish mineral of the ruby silver group, galena, and locally in the vugs a little fibrous cerusite. Associated with these minerals, but in general not abundant, are pyrite, arsenopyrite, hematite, and sphalerite. The pyrite and arsenopyrite are widely disseminated through the replacement quartz for 30 feet or more from the vein.

Nearly all the ore shows free gold in rounded nugget-like particles, the largest of which are the size of a pin head.

Most of the gold is of a pale brass or yellowish-white color, much lighter than the gold of Lincoln Hill or Spring Valley. Some of it is alloyed with about 50 per cent of silver and seems to be undoubtedly electrum.

A microscopic section of the ore shows chiefly a gangue of medium to fine-grained crystalline quartz. Considerable sericite is present in places and a little fluorite, pyrite, and arsenopyrite. In this gangue the gold occupies very irregular interstices and fractures. In general, it is associated with and in part enveloped in a dark-reddish opaque mineral, which is probably pyrargyrite, though it was not determined owing to the difficulty of isolating it. It is probably an important source of the silver obtained from the ore.

Three periods of silicification are recorded. The first preceded the deposition of the ore minerals. Crushing, followed by ore deposition, marked the second period, which probably was not sharply separated from the first. A third and less general silicification is indicated by veinlets of barren quartz.

Where opened by the Hunter 30-foot shaft on the north end of the June No. 2 claim, the middle vein shows a width of 16 inches of partly banded or streaked gold-quartz ore of good grade. At another opening a few hundred feet to the south the ore carries also galena, considerable silver sulphide, and some arsenopyrite and pyrite.

On the D'Armond lease, where opened by a shallow shaft, trench, and cut, the lower or west vein carries on the hanging wall side a shoot of rich gold-silver-lead ore 2 feet wide. This ore, which is banded, carries about 20 per cent lead, which occurs in the form of galena.

A few hundred feet to the south, on the Lowry lease and on the north end of the Blossom claim, the same vein is about 3 feet wide and has much green chloritic rock in the foot wall.

The east or Hansen vein, where opened on the Wilson lease by a 12-foot shaft and cut, has a width of 15 inches and is all good gold ore that contains some galena. Two tons of the ore, sacked on the dump, are said to average about $75 to the ton.

At the Prince opening, 400 feet to the north, where the dip flattens to 35°, the vein is 8 feet wide and is composed chiefly of glassy quartz, containing a little hematite and sphalerite.

AGE OF DEPOSITS OF THE ROCHESTER DISTRICT.

From the close connection in origin of the deposits of the Humboldt Range with the folding and deformation of the Triassic and Jurassic rocks, Ransome[1] regards the deposits of the Humboldt Range as probably belonging to the early Cretaceous, like the gold veins of the Mother Lode belt in California.

To this view the Rochester ore deposits seem in general to conform. Their formation accompanied or followed the pronounced sheeting and jointing of the region. As regards origin they have been referred (p. 350) to the work of ascending hydrothermal magmatic solutions. The nearest exposed mass of intrusive rock that appears adequate to account for these solutions is the considerable area of granite 7 miles to the north in Wrights Canyon, on the east slope of the range, which, as described on page 333, intrudes both the Koipato and Star Peak formations.[2] The time of this intrusion is shown to be at least post-Triassic and is regarded by Louderback as probably post-Jurassic. The ore deposits therefore belong to the same general period of intrusion as the batholiths of California and western Nevada, in connection with or following whose intrusion in sedimentary and other rocks ore deposits have been widely formed.

In its southern extension the granite of the Wrights Canyon mass very likely underlies and intrudes the rocks in the Rochester area, for these batholithic intrusions are known to have taken place on a large scale. This view, as suggested by Jones,[3] is supported by the occurrence of tourmaline in the deposits of Lincoln Hill and Spring Valley, which mineral is as a rule closely associated with intrusive granitic rocks. Moreover, granitoid material in the gravels of Walker Gulch, adjoining American Canyon, indicates the presence of granite in the near-by axial portion of the range.

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[1] Ransome, F. L., op. cit., p. 46.

[2] Louderback, G. D., op. cit., pp. 317–318.

[3] Jones, J. C., loc. cit.

The deposits accordingly appear to belong to the late Mesozoic metallogenetic epoch.[1] From the presence of tourmaline, arsenopyrite, and other minerals commonly of deep-seated origin, it may be concluded that the deposits formed at considerable depth in what has been termed the deep-vein zone.

FUTURE OF THE DISTRICT.

From the deep-seated character of the deposits and their close association with the major geologic structures, which are shown to have been impressed upon the rocks of the region from the tops of the mountains to some distance below the floors of the deepest valleys, the deposits may reasonably be expected to extend to considerable depth. In the sulphide zone, however, they will probably become leaner and more regular in tenor than in the present workings, which are chiefly in the oxidized zone.

PLACERS.

AMERICAN CANYON.

Placer mining was at one time an important industry in the southern end of the Star Peak Range. Activity centered chiefly in American Canyon and at Fitting in Spring Valley, 2 miles to the north. Early in the eighties these places contained flourishing placer camps. In American Canyon operations continued active until about 1895. Ransome[2] says:

> The placers were first worked by Americans, who are reported to have taken out gold to the value of about $1,000,000. The ground, however, soon passed into the possession of Chinese, who formed a considerable settlement in American Canyon and mined the gravels with skill and assiduity by drifting from countless narrow shafts ranging from 40 to 85 feet deep. How much gold they obtained is unknown, but some estimates, doubtless much exaggerated, place the total at about $10,000,000.

Under the Chinese system the ground, it is said, was subdivided into blocks 15 feet square.

In American Canyon, at the time of the writer's visit, two Chinese, the only inhabitants in the camp, working with a rocker, continued to win gold from the surface of the former rich diggings. After a heavy rain a few nuggets may still be picked up on the old dumps, but the ground is said to be almost worked out and was seemingly being abandoned.

WALKER GULCH.

In a parallel gulch, however, about half a mile north of American Canyon, at an elevation of about 4,700 feet, Mr. R. E. Walker, manager of the Dixie mine, has recently discovered what appear to be new and valuable deposits. These deposits underlie several hundred feet of basalt and apparently are the gravels of an ancient stream that flowed over Triassic limestone. These gravels are Tertiary or older.

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[1] Lindgren, Waldemar, Metallogenetic epochs: Econ. Geology, vol. 4, pp. 415, 418, 1909.

[2] Ransome, F. L., op. cit., p. 12.

Where seen by the writer, at the east edge of the basalt, the deposits appear to extend without interruption beneath the basalt, which here forms a scarp, 10 to 12 feet high, across the channel. At the time of the writer's visit, however, no excavation had been made to prove that the gravels extend under the basalt. About 100 feet east of the basalt a 60-foot shaft had been sunk in the deposits by Mr. Walker. This shaft shows that the deposits are similar to those worked in American Canyon except that the gravels are apparently more rounded and waterworn and contain considerable granitoid material. They are clearly fluviatile and are reported to show gold nearly all the way down in the shaft. At the bottom of the shaft is blue limestone, the surface of which slopes southward, toward the middle of the channel, the dip being 30°–40°.

More recently Ernest G. Locke,[1] manager of the Lockslee Gold Placer Mining Co., which has purchased the deposits, reports that he has made a thorough exploration at different points and proved by excavations made beneath the basalt that the deposits, having a width of 500 feet and a length of half a mile, underlie the lava, which in places has baked and stained them red along the contact.

South of the Walker shaft, at a point which was thought to be over the middle of the channel, Mr. Locke sank a 200-foot shaft without reaching bedrock. From the bottom of this shaft a crosscut reached the north rim rock at 130 feet, and a 65-foot drift was run to the west parallel with the channel. With new machinery now being installed development work, it is said, will be continued to the bottom of the channel, where it is hoped the pay streak may be well defined. According to Ransome,[2] the Midas shaft, also sunk in American Canyon some years ago, is 200 feet deep and all in gravels and clays.

According to Mr. Locke, the gravels dip 30°–45° E. down the mountain side and seem to have been deposited by a stream flowing eastward into Buena Vista Valley, perhaps into Lake Lahontan, which formerly occupied that valley. This comparatively steep dip may be due in part to orographic uplift since deposition.

Like the Walker shaft, the Locke shaft is said to show gold from the surface down. The gold is coarse and the particles in general average about a fifth of a cent in value, though some were estimated to have a value of a cent and a half. The gravels penetrated by the shaft are estimated by Mr. Locke to average from 75 cents to $1 to the cubic yard; those in the drift and the crosscut average somewhat less. The gold is worth approximately $17 an ounce.

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[1] Letter of Feb. 3, 1914.

[2] Ransome, F. L., op. cit., p. 37.

The fact that the deposits in the drift and crosscut appear to average less than those penetrated in the shaft suggests that the gold may be concentrated at certain horizons, as in the deposits of American Canyon, where the pay streaks were found at the depths of about 40, 60, and 85 feet, respectively.[1]

Although the steep streamward slope of the rim rock may account for the fact that the gold is not concentrated on the bedrock thus far exposed, and although such a slope would strongly favor concentration in the bottom of the channel, it should be remembered in formulating working plans that in American Canyon apparently no gold was taken from off the bedrock.[1]

SPRING VALLEY.

At Spring Valley or Fitting, 3 miles northeast of Rochester, the Federal Mines Co.'s dredge, the only dredge operating in Nevada, is said to have had a very profitable season during the years 1913 and 1914. In 1913 it worked chiefly in deposits that average about 22½ cents a cubic yard, but the excavations did not extend to bedrock. The last clean-up, made early in June, 1914, is said to have shown a recovery of 30 cents to the cubic yard. The dredge is said to handle from 1,500 to 1,600 cubic yards a day with gasoline power. With electric power its capacity would be greatly increased. The gold bullion produced from these placers in 1911 ranged from 0.696 to 0.730 fine.[2]

ROCHESTER CANYON.

For many years it has been the custom of a few prospectors to procure their annual "grub stake" from the gold placers in Rochester Canyon. Hardly any evidence of such work was observed, however, in the writer's hasty trip through the canyon. At the time of the writer's visit, however, the gravels were being exploited from 1 to 2 miles below Lower Town, where they are said to have a thickness of 85 feet and to yield fair prospects. They vary from 50 to several hundred feet or more in width. A shaft had been sunk through them to bedrock, and drifts were being run from the shaft to the rim rock. The bedrock here, as shown by material from the bottom of the shaft, is dark-purple quartzite.

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[1] Ransome, F. L., loc. cit.

[2] Heikes, V. C., U. S. Geol. Survey Mineral Resources, 1911, pt. 1, p. 681, 1912.

The deposits consist of a heterogeneous mixture of the gulch gravels and finer detritus derived from the adjacent hill slopes. Their gold was doubtless derived through erosion from the lodes in Lincoln Hill and at the Limerick mine.

WEAVER CANYON.

Whether Weaver Canyon has been prospected for placers was not learned. If it has not, attention may be called to the fact that the unusually large quantity of gold contained in the ore of the Colligan and other mines at its head suggests that this canyon may be a good one to prospect.

SOUTH AMERICAN CANYON.

In South American Canyon, heading at the east base of Nenzel Hill, excavations show some work to have been done for placers but apparently not with good results.

LIMERICK CANYON.

Recently (April, 1914) placer gold has been discovered in the head of Limerick Canyon, in the south end of the Nenzel Hill mineral belt, just north of the town of Panama at an elevation of about 6,300 feet. The location, according to Mr. E. B. Mills,[1] superintendent of the Rochester Mines Co., who has kindly supplied the substance of the following statement, is on a low ridge covered with sagebrush, and the gravel deposit extends about 6 feet in depth to bedrock. Two men with a rocker are said to take out from $60 to $100 a day. There seems to be no trace of the ledge or bedrock source of the gold in the vicinity. Later reports state that the surface overburden of 1 to 2 feet of the deposit is being removed by plow and scraper and the balance hauled to water for treatment.

According to reports received in September, the deposits have an extent of nearly a mile. The pay gravel is from 12 to 15 inches thick and averages from $12 to $15 to the cubic yard. It lies on bedrock, where it appears to follow certain channels, and in places it is covered by 4 to 10 feet of overburden consisting of barren wash. Ten or twelve outfits are at work. Dry washing is being tried, it is said, with fair success, as the gold is mostly coarse.

Special interest attaches to this deposit for several reasons. In the first place, it lies just over the range from the deposits of Walker Gulch, and the intervening area may contain lode deposits from which the placers on either side of the crest may have been derived. It should be prospected with care. In the second place, if the deposits are water-laid gravels, as they are said to be, they, like the deposits of Walker Gulch, apparently represent an ancient stream channel which may have crossed the range by way of Spring Valley Pass. This pass, now the lowest in the range, has since been eroded to a slightly lower level and any gravel that it may have contained has been removed. In the third place, the occurrence of ancient auriferous channels so near the crest of the range suggests that they, too, may have been important contributors to the Spring Valley and American Canyon placers.

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[1] Letter of Apr. 8, 1914.

580-N

THE ELLISTON PHOSPHATE FIELD, MONTANA.

By R. W. Stone and C. A. Bonine.

INTRODUCTION.

The first reported discovery of rock phosphate in Montana was made by H. S. Gale, of the United States Geological Survey, at Melrose in October, 1910. This phosphate, at the same geologic horizon as that in the phosphate fields of Idaho, Wyoming, and Utah examined by Survey parties in 1909, suggested the strong possibility of its occurrence in western Montana over an extensive region where Carboniferous rocks outcrop. In 1911, while examining Northern Pacific Railway land-grant lands for the purpose of classification, J. T. Pardee, of this Survey, found rock phosphate at three localities in western Montana—(1) in the Garnet Range, 6 miles north of Garrison; (2) at Philipsburg, on the south slope of Flagstaff Hill; and (3) half a mile east of Elliston; and R. W. Stone discovered rock phosphate 2 miles east of Cardwell, at the summit of the cliffy slope west of Jefferson River. The demands of the work in hand did not permit detailed study of these deposits in 1911. The Melrose area was mapped by R. W. Richards in 1912, but it was not until September, 1913, that an investigation of the deposits discovered by Pardee was undertaken.

A detailed examination of the phosphate field at Elliston was begun September 8, 1913. Snow covered the country above an elevation of 6,000 feet on the 16th of the month but lasted only one day. On the 22d 6 inches of snow fell and interfered with work in the woods for five days. A third storm began October 5, and the camp outfit was stored for the winter October 7, with 2 feet of snow on the land under examination. In spite of the short time thus available the main geologic features were worked out and the outcrop of the phosphate bed was located.

The accompanying map (Pl. IX) shows the location of the phosphate outcrop with relation to land lines and the location of some of the other geologic features. The geologic boundaries actually traced are shown in a solid line. A broken line is used where the location of the boundary is only approximate, as in areas of andesite and granite that were mostly in timber with snow on the ground at the time of the examination. The locations on the map were determined by stadia, plane-table triangulation, or paced traverse tied to corners. The map shows 67 section or quarter-section corners that were found

The writers were assisted in the geologic mapping and prospecting of the phosphate by J. E. Richardson, jr.

GEOLOGY.

GENERAL RELATIONS.

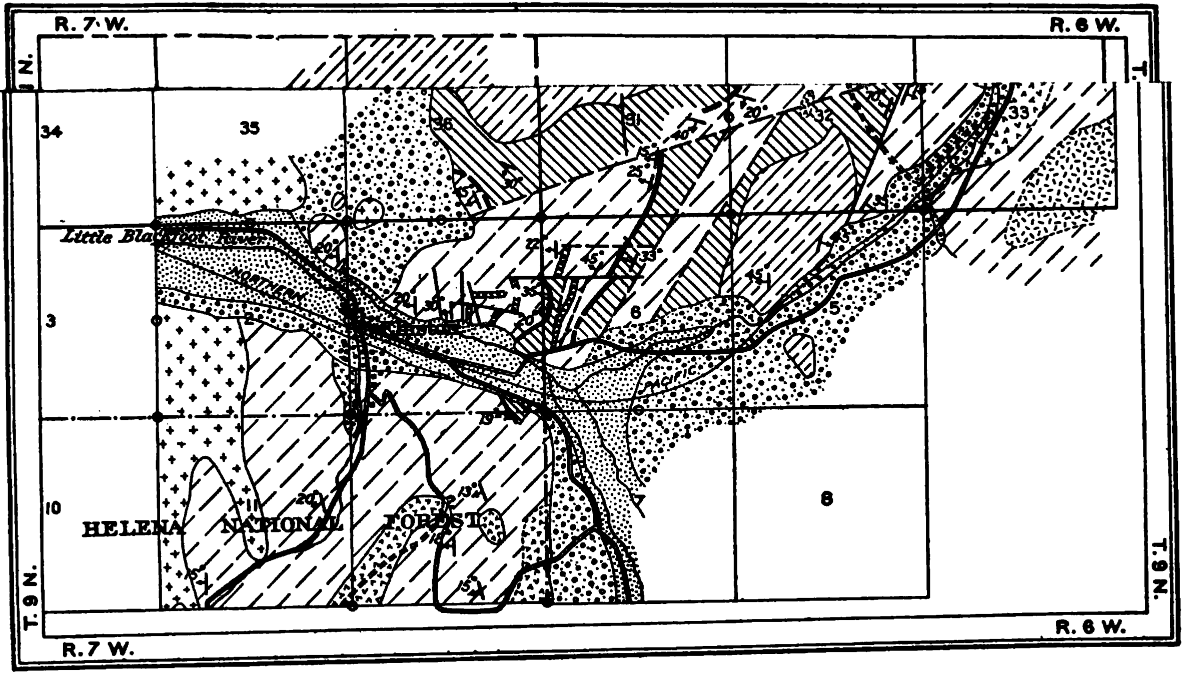
In the Western States rock phosphate occurs in sedimentary beds of Carboniferous age at about the same geologic horizon over a considerable area. Warping or breaking of the earth's crust, igneous intrusion, and erosion have caused the extensive phosphate beds, originally laid down horizontally to be separated into detached areas and tilted at various angles, in some places even vertically. From the regions lying between the phosphate fields hundreds and probably thousands of feet of strata have been removed by erosion.

The sequence and character of the Carboniferous sediments vary rom place to place throughout the region in which phosphate was laid down, but the general relation is fairly constant in western Montana. A knowledge of the sequence of the sedimentary rocks closely related to the phosphate horizon is essential to intelligent prospecting for the phosphate. In many localities the massive blue Madison limestone, which is about 1,000 feet thick and conspicuously exposed, is a guide to the phosphate bed which lies from 400 to 700 feet above it with sandy shale and quartzite between. Massive beds of quartzite, some of which are nearly pure white and strong ledge makers, are separated from the uppermost limestone by 100 to 300 feet of red sandy beds. The phosphate occurs near the top of these quartzite beds. The phosphate commonly lies just above a ledge of massive white quartzite and is overlain by black cherty rock. This statement applies to horizontal beds or to those tilted at a low angle. If the beds are nearly vertical, the phosphate occurs on the side of the quartzite beds farthest from the Madison limestone. The distance between the top of the Madison limestone and the place where phosphate float should be found varies with the attitude of the beds and with the relation of the outcrop to the hill slope.

Above the phosphate horizon are sandstones and shales of Mesozoic age, which are of particular interest in this connection only because they form the cover of the phosphate bed.

SEDIMENTARY ROCKS.

Details of stratigraphy have not been studied, nor are they essential in an economic report. The formations will be mentioned briefly, however, in the order of their age. The rocks range in age from early



MAP OF THE ELLISTON PHOSPHATE FIELD, MONTANA.

Carboniferous (Mississippian) to Recent. They are of both sedimentary and igneous origin.

Madison limestone (*Mississippian*).—The Madison limestone is extensively exposed north of Elliston, and the position of its upper part is shown on the map. As the formation is about 1,000 feet thick, its outcrop is wide where the beds lie at a low angle. In general it is a thick-bedded blue limestone, weathering white or light gray, somewhat fossiliferous and carrying irregular cherty nodules. The beds where highly tilted commonly make prominent outcrops. A detached small area of Madison limestone is partly exposed by a quarry at the limekilns 2 miles east of Elliston. The main outcrop of limestone in this field lies west and north of the phosphate outcrop, as shown on the map.

Quadrant (*?*) *quartzite* (*Pennsylvanian?*) *and Phosphoria formation* (*Permian?*).—The Madison limestone is overlain by about 700 feet of later Carboniferous rocks, of which the lower 640 feet is tentatively correlated with the Quadrant quartzite of the Three Forks quadrangle and other areas to the southeast, and the upper 80 feet, which contains the phosphate beds, is correlated with the Phosphoria formation of Idaho and southern Montana. Where the rocks are tilted at a high angle the outcrop of these formations is narrow; but in the northern part of the field, where the dip is less than 45°, the outcrop is a quarter of a mile or more wide. It extends in an S-shaped belt from the rhyolite in sec. 33, T. 11 N., R. 6 W., to sec. 36, T. 10 N., R. 7 W., where it is hidden by Tertiary lake deposits just north of Elliston.

The following section was measured where the beds stand vertical but are not particularly well exposed:

Section at northwest corner of sec. 20, T. 10 N., R. 6 W.

	Feet.
Phosphoria formation:	
Sandstone and shale, soft, greenish brown	75
Phosphate rock, shown by bluish-white float	5
Quadrant (?) quartzite:	
Quartzite, white, massive, ledge maker	50
Quartzite, gray, pink, and white, interstratified with shale.	210
Sandstone and shale, concealed	200
Quartzite, gray and pink, variegated	30
Shale, sandy, soft, reddish in places	150
Madison limestone:	
Limestone, blue, weathers white	1,000+

The black chert in some places overlying the phosphate bed seems to be absent at this point, though it is well exposed in sec. 6, T. 9 N., R. 6 W.

Mesozoic formations.—The beds overlying the phosphate are mainly thin-bedded buff-weathering sandstone and shale and arenaceous limestone. Black chert is common immediately above the phosphate.

Not far above it is a conspicuous thick-bedded quartzose sandstone which is hard enough to make ledges and commonly develops coarse talus. This sandstone carries numerous minute particles of black chert, which give it a speckled appearance. It is well exposed in the hill half a mile northeast of Elliston depot.

No place was found at Elliston where the beds younger than the phosphate could be measured successfully. The stratigraphic section is complicated by faults and by sills of andesite porphyry.

Cenozoic deposits.—Deposits of sand, gravel, clay, and tuff, commonly known as Tertiary lake beds, occur just north of Elliston. An unconsolidated deposit of gravel in the SW. ¼ sec. 31, T. 10 N., R. 6 W., probably may be correlated with the post-Tertiary and preglacial terrace gravels found in this part of the State.

At the forks of Blackfoot River, east of Elliston, there is a stretch of hummocky topography resembling glacial moraine. Alluvial gravel, sand, and silt, extensive enough to be shown on a map of the scale here used are found only near Elliston.

IGNEOUS ROCKS.

Andesite.—The oldest igneous rock in the Elliston field is andesite, a porphyritic rock, occurring in several varieties, which was originally poured out on the surface in a great sheet and also interbedded with Mesozoic sediments. Remnants of this flow now cap some of the ridges. One of these remnants is along the crest of the divide between Elliston Creek and Little Blackfoot River in sec. 12, T. 9 N., R. 7 W., another, in which pyroxene phenocrysts are prominent, crowns the ridge at the northeast corner of sec. 18, T. 10 N., R. 6 W. From this point for 2 miles or more northward small patches of andesite occur intermittently along the crest. Other areas of andesite are shown on the map, but their boundaries are less certain, as they occur in timber and away from the phosphate horizon.

Granite.—Granite, or more technically quartz monzonite, outcrops in small areas in the east half of the field. These croppings are outliers of the Boulder batholith, a great mass of intrusive granitic rock extending uninterruptedly from Blossburg and the vicinity of Helena to the Highland Mountains, 16 miles south of Butte. An intrusion of granite near the northeast corner of sec. 16, T. 10 N., R. 6 W., has altered the invaded sandstone to beds of almost solid garnet rock, with calcite, tourmaline, actinolite, epidote, and diopside. The map shows two long, narrow bands of granite on the west side of Dog Creek. These are the approximate locations of float found along the mountain side in timber. Bedrock was not discovered, and the shape and character of the intrusions are not known. The rock appears to be hornblende granite porphyry, probably an offshoot from the main mass of quartz monzonite.

Rhyolite.—Rhyolite occurs west of Elliston and also on the Continental Divide east of Dog Creek. These areas are merely remnants of lava flows poured out over this region, probably in Miocene time and when the topographic relief was similar to that of the present. Much larger areas of rhyolite are to be seen farther west on Blackfoot River, particularly near Avon.

STRUCTURE.

In the north end of the Elliston phosphate field the rocks form a structural trough or syncline having a northwest-southeast axis in the valley of Dog Creek. In the south half of the field the rocks form a structural arch or anticline, the axis of which is along the west side of sec. 31, T. 10 N., R. 6 W., parallel with and west of the synclinal axis. This arch ends abruptly, however, in fault blocks, the intricate structural details of which have not been fully determined.

The fault blocks are tilted at angles of 10° to 90°, and the phosphate bed is traced with little difficulty, but the exact position of the faults is hard to determine. Abrupt changes from nearly horizontal to vertical bedding and the offsetting of andesite sills afford abundant evidence that faulting has taken place, but a mantle of gravel and talus masks the bedrock at vital points for the determination of the faults.

PHOSPHATE.

PHYSICAL CHARACTERISTICS.

The phosphate rock in western Montana is readily distinguished by its finely oolitic texture, thin bluish-white coating on weathered surfaces, heavy specific gravity, and peculiar odor.

Texture.—In the Elliston field the oolitic texture is readily recognizable. The oolites or ovules, which form a very large percentage of the rock, range for the most part from 0.01 to 0.1 inch in diameter. In the rich rock near Elliston a large percentage of the oolites are about 0.04 inch in diameter, or smaller than the head of a common pin. The oolites in much of the rock are so tightly cemented that they are broken through by joints or fractures. In the weathered outcrop of the richest rock the oolites are freer and fragments show miniature mammillary surfaces from which the rounded nodules can be easily separated. Even to the unaided eye it is apparent that some of the oolites have a distinct concentric structure. By the aid of a magnifying glass it is seen that some have a white center surrounded by a dark band with a white edge; others a dark center, a succession of white and dark bands, and a white edge. Other oolites appear to be a solid homogeneous chalk-white substance and some have a central cavity. Although at first glance these ovules appear to be round, closer examination shows that most of them are spheroidal and some discoidal. This shape seems to be inherent rather than induced by pressure, for parallelism of elongated ovules is not produced.

Weathering.—The fresh rock phosphate of this field is dark gray to black in color, but the weathered surface is characterized by a bluish-white tinge known as phosphate bloom. Each individual oolite of a thoroughly weathered surface is white or bluish white, and where the oolites are abundant they commonly give this color to the surface. Phosphate rock is found in which not only the oolites but the matrix weathers to a nearly pure white, and the float may then be as white as if it had been given a thin coat of kalsomine. There are outcrops—for example, near the north quarter corner of sec. 6, T. 9 N., R. 6 W.—in which a red matrix gives a red or pink tinge to the weathered surface. The phosphatic character of the rock is readily recognized, however, by the white oolites.

Specific gravity.—A rich phosphate rock is noticeably heavy compared with quartz, chert, or other rocks of the same volume. The average specific gravity for rock containing 70 per cent of tricalcium phosphate is about 2.9.

Odor.—Phosphate rock when freshly broken gives off for a moment a fetid odor. The fume is not exactly bituminous nor sulphurous but is very characteristic; it is not particularly disagreeable. Some rock gives off so strong an odor when rapidly broken that it can be smelled readily at a distance of 3 or 4 feet. It is not believed that the intensity of the odor given off is in proportion to the phosphatic content.

ORIGIN.

The origin of the western phosphate has been little studied owing to the short time that has elapsed since the discovery and to the lack of development of the deposits. The scope of the present paper will not permit a discussion of the hypotheses advanced to explain its origin. The facts observed in the field, however, indicate that it is a bedded sedimentary deposit laid down in Pennsylvanian or Permian time in waters rich in phosphate of lime. The abstraction of this phosphate of lime and its deposition in oolitic bodies may have been accomplished entirely by chemical means or by phosphate-secreting marine organisms.

THICKNESS AND COMPOSITION.

The phosphate bed was completely exposed by prospect trenches at four points. One natural exposure of the entire bed was found. At four other places an unsuccessful attempt was made to cut a trench down to the bed. One of these places was an old cut opened by some prospector who evidently recognized the material but failed to reach bedrock. The five localities where the bed was wholly uncovered are indicated on the map (Pl. IX) and described in detail below. In the tables are given the thickness and character of beds and analyses of samples from prospect trenches opened by the writers in the Elliston field. The descriptions begin with the northeast end of the outcrop.

Float phosphate was found in the E. ½ sec. 32, T. 11 N., R. 6 W., and in sec. 33 up to the boundary of an area underlain by rhyolite. This float was found by searching in small patches around the base of trees where snow had melted off. No attempt was made to dig a trench because snow prevented making a careful choice of location. The line shown on the map is the location of abundant float. A sample for analysis was taken by gathering small fragments of float at many points along half a mile of outcrop. An analysis of the sample collected in this manner gave 29.62 per cent P_2O_5, equivalent to 64.6 per cent tricalcium phosphate.

Close beside the road in the NW. ¼ sec. 32, T. 11 N., R. 6 W., a prospect pit was found in which considerable white phosphate rock had been unearthed. The abundance of float warranted digging, but an attempt on the part of the writers to uncover bedrock was as unsuccessful as that of the earlier prospector. A sample was taken by breaking chips from many pieces on the piles around the trench. These were mixed and quartered, and the quarter retained showed on analysis 35.85 per cent P_2O_5, equivalent to 78.3 per cent tricalcium phosphate. This is the highest percentage of phosphate obtained in the Elliston field and may be accounted for by the fact that the rock was more weathered than the other samples. The weathering of phosphate rock tends toward enrichment from 3 to 5 per cent, owing to leaching of the more soluble lime carbonate.

Float was found across sec. 30, T. 11 N., R. 6 W., on clear slopes and in the woods 250 feet north of the southeast corner of sec. 24, T. 11 N., R. 7 W. Although several inches of snow covered the ground, phosphate was discovered around the base of trees where the snow had melted away for a few inches. A trench was dug on the crest of a ridge in section 24, where the beds strike N. 80° E. and dip S. 24°. The following section shows the character of the rock at this point:

Section of phosphate bed in trench in SE. ¼ SW. ¼ sec. 24, T. 11 N., R. 7 W.

No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
	Quartzite, hard, black, cherty.	*Per cent.*	*Per cent.*	*Ft.*	*in.*
43	Quartzite, phosphatic	12.98	28.3	1	5
44	Phosphate	30.55	66.6	3	4
	Quartzite, hard, dark.				

Float is plentiful through the woods to the west of this trench. A second trench was dug on a ridge top in section 35. The beds at this point strike N. 50° W. and dip 42° NE. at the top of the section and 35° NE. at the bottom. The section is as follows:

Section of phosphate bed 1,000 feet north of southwest corner of sec. 35, T. 11 N., R. 7 W.

No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
	Quartzite, sandy.	*Per cent.*	*Per cent.*	*Ft.*	*in.*
55	Phosphate, cherty	33.24	72.5	1	3
	Phosphate, good			1	8
	Shale, yellow				3
	Phosphate, good			2	0
	Chert, phosphatic				3
	Quartzite.				

The analysis includes the four phosphatic layers but not the 3-inch parting. Several pounds of material from these four beds was crushed, mixed, and quartered at the trench to give an average sample.

In ascending the east fork of Trout Creek phosphate float is first seen in the road beside a cabin near the line between secs. 1 and 2, T. 10 N., R. 7 W. This float has come down a steep hillside, and the outcrop is considerably east of the cabin. From Trout Creek southeastward across the head of Gold Canyon Creek for a distance of 3 miles the rocks are so metamorphosed and distorted that no trace of the phosphate could be found. At the east side of an old sheep corral at the northwest corner of sec. 20, T. 10 N., R. 6 W., float was found and traced continuously down a ridge to the south quarter corner of sec. 20. Between this quarter corner and the creek, 1,000 feet to the south, phosphate float is abundant; but several attempts to reach bedrock by shallow trenching were unsuccessful. Float phosphate was traced across the NW. ¼ NW. ¼ sec. 32, but could not be found near the west quarter corner of this section.

Near the center of sec. 31 the offsetting of the uppermost bed of Madison limestone and overlying red sandy shales is apparent, but the writers were unable to trace the phosphate up to the fault line. It is readily traced, however, from a point near the center of sec. 31 southward three-quarters of a mile along the crest of a quartzite ridge. Float was found at the highway on a direct continuation of this course, but the bed was not discovered in some places in the last quarter of a mile. This bed was exposed with a little trenching near the north line of sec. 6, where the following section was revealed:

Section of phosphate bed 800 feet south of north quarter corner of sec. 6, T. 9 N., R. 6 W.

No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
	Chert, black.			
	Shale, cherty.	*Per cent.*	*Per cent.*	*Ft. in.*
36	Phosphate	11.89	26.0	2 11
	Chert, slightly phosphatic			2 7
38	Phosphate	15.31	33.4	6
	Quartzite.			

Outcrops and two other small trenches in the immediate vicinity showed beds similar in thickness and quality to those of the above section.

In 1911 J. T. Pardee discovered float phosphate close to Elliston in the NE. ¼ SE. ¼ sec. 1, T. 9 N., R. 7 W. The locality is on the east side of a small gulch and just west of the upper bridge over Little Blackfoot River. The float was found a few feet above flood-plain level on the dip slope of a great cliffy quartzite ledge. An analysis of this float[1] gives 30.0 per cent P_2O_5, equivalent to 65.5 per cent $Ca_3(PO_4)_2$. This float is from an outcrop about half a mile long in a fault block. It is easily traced up the dip slope a few rods east of the east quarter corner of sec. 1, over the crest of the knob and around the east side to the place where the writers uncovered the entire bed by a trench, as follows:

Section of phosphate bed in trench in SW. ¼ NW. ¼ sec. 6, T. 9 N., R. 6 W.

No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
		Per cent.	*Per cent.*	*Ft. in.*
	Chert, phosphatic			1 0
	Shale, yellow			3-6
29	Phosphate	28.25	61.6	5 9
	Quartzite, yellowish			2
	Concealed			8 0
	Quartzite, white, massive.			

The phosphate bed can be traced by float about 200 yards northward from this trench to the locality where an unsuccessful attempt was made to uncover the bed. It was not found north of the gulch. Here the quartzite ledge on the south side of an old road opposes younger sandstone on the north side, indicating the presence of an east-west fault.

About three-quarters of a mile southeast of the Elliston depot, in the NE. ¼ NE. ¼ sec. 12, T. 9 N., R. 7 W., a trench was dug 8 feet long and 2½ feet deep, which uncovered an 8-inch bed of phosphate between quartzite below and black chert above. This phosphate was believed to be the same as the lower bench of the exposure in section 6, 1 mile to the northeast, but heavy cover prevented excavating for the upper bench. The 8-inch bed contains 16.15 per cent of P_2O_5, which is equivalent to 35.1 per cent $Ca_3(PO_4)_2$. This analysis is very close to that of the 6-inch bed in the first table on page 381.

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[1] U. S. Geol. Survey Bull. 530, p. 290, 1913.

It is apparent from its position and attitude that the quartzite ledge which is exposed along the road at the section corner three-quarters of a mile southeast of Elliston, and on which this phosphate bed lies, is the same as that which makes a cliff at the bridge, one-third of a mile farther north. This bed would underlie Elliston if not interrupted by faults.

The last exposure of phosphate to be described is that nearest to Elliston; but in some ways it is the least important, although the phosphate is of high grade and the bed has the greatest thickness measured in this field. The locality is half a mile north of east of Elliston depot, on the north side of the river, 20 feet or more above the flood plain. It is a quarter of a mile west of the west end of the quartzite cliff near the upper bridge. At this point the beds in a natural exposure strike north and are vertical. Beds on three sides dip at low angles and the outcrop of the phosphate is only a few rods long. There is every indication, therefore, that the bed is in a small fault block. The section is as follows:

Section of phosphate bed in SW. ¼ NE. ¼ sec. 1, T. 9 N., R. 7 W.

No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
		Per cent.	*Per cent.*	*Ft.*	*in.*
25	Chert, black, phosphatic	15.52	33.84	1	10
26	Chert, black, nonphosphatic	Less than 5	....	3	10
27	Phosphate	29.82	61.1	6	0
28	Phosphate, spotted, cherty	19.96	43.7	1	6
	Limestone, soft, yellow, shaly.				

From the above data and the accompanying map it is seen that a bed of phosphate rock ranging in thickness from 3 to 5 feet and averaging approximately 65 per cent in tricalcium phosphate outcrops for 9 miles in the north half of the Elliston field. An estimate of the tonnage of phosphate rock in the northern part of the field is presented below, the land underlain by the phosphate bed in secs. 1 and 2, T. 10 N., R. 7 W.; secs. 19, 30, 31, 32, and 33, T. 11 N., R. 6 W.; and secs. 23, 24, 25, 26, 27, 34, 35, and 36, T. 11 N., R. 7 W., being considered as equal to 7 square miles, and any phosphate land in the northwest corner of T. 10 N., R. 6 W., being omitted.

At a specific gravity of 2.9 phosphate rock weighs 181.8 pounds to the cubic foot, or 3,959.6 short tons to the acre for every foot in thickness of the phosphate bed. This makes 2,534,144 tons to the square mile for every foot of flat-lying bed, or 70,956,032 tons of phosphate rock in the 7 square miles, the bed being estimated to average 4 feet in thickness. As the bed does not lie flat and there are differences of 1,200 feet in elevation of the outcrop, the actual tonnage would be greater.

In the south half of the Elliston field the phosphate bed stands nearly vertical along about 2 miles of its outcrop, but near Elliston it is so faulted that an estimate of the area underlain by it is difficult. On the assumption, however, that this part of the field contains the equivalent of 3 miles of outcropping bed that could be mined to a depth of half a mile, there is in the south half of the field 1½ square miles underlain by phosphate; and as the few measurements in this part of the field suggest an average thickness of 4 feet, an estimate is possible of 15,204,864 tons of phosphate rock in the south half, making a total of more than 86,000,000 tons in the whole Elliston field.

ACCESSIBILITY AND USE.

The phosphate in the south half of the Elliston field is within 2 miles of the Northern Pacific Railway and readily accessible to it. The farthest point in the northern part of the field is between 6 and 7 miles from the railway by way of Dog Creek valley, down which there is an easy grade.

Rock phosphate is used in the manufacture of fertilizer. In the process the rock is finely ground and mixed with a nearly equal part by weight of sulphuric acid. The result of this mix is an acid calcium phosphate which, when dried and pulverized, is the substance sold as superphosphate. In this form the phosphoric acid is more readily available as a plant food than it is in the original or raw state.

There has been no development of these deposits owing to their recent discovery and to the lack of markets sufficiently near to justify mining and reduction. The demand for fertilizer products in the Western States is not large, owing to the lack of intensive cultivation and the newness of the agricultural lands; but there is a growing tendency to use fertilizer where the land is farmed extensively, especially in the Middle West. The western phosphate deposits are favorably situated to meet a demand from this section of the country and will probably be utilized in the future.

580-0

THE RUTILE DEPOSITS OF THE EASTERN UNITED STATES.

By Thomas L. Watson.

INTRODUCTION.

The titanium-bearing minerals comprise more than 60 distinct species, grouped under a variety of mineral and chemical forms, chiefly as oxides, titanates, titano-silicates, silicates, columbates, and tantalates. These minerals are widely distributed in a variety of associations and in such quantity as to make titanium a relatively abundant element. Clarke[1] estimates the amount of titanium in the solid crust of the earth to be 0.44 per cent, equivalent in oxide to 0.73 per cent, the element thus standing in the ninth place in the scale of abundance, next to potassium.

Most of the titanium-bearing minerals, however, are rare and are only of scientific interest. The largest concentrations of the element are as oxide (rutile), as iron titanate (ilmenite), and in iron ferrate (magnetite) as intergrown ilmenite. Of these three forms the principal source of the element at present is rutile. The known workable deposits of rutile, however, are extremely few and widely separated, and as the demand for titanium has greatly increased in the last few years it has been necessary for some uses to turn to ilmenite or highly titaniferous magnetites.

This paper briefly summarizes present knowledge of the geology of the rutile deposits in the eastern United States and for the sake of comparison discusses several foreign deposits, each of which has produced some rutile. Of the known deposits in the United States only those in Virginia are of commercial importance. These have been made the subject of a special report[2] by the Virginia Geological Survey, which was preceded by a preliminary paper on the rutile deposits of Amherst and Nelson counties.[3]

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[1] Clarke, F. W., U. S. Geol. Survey Bull. 491, pp. 32, 33, 1911.

[2] Watson, T. L., and Taber, Stephen, Geology of the titanium and apatite deposits of Virginia: Virginia Geol. Survey Bull. 3-A, 308 pp., 1913.

[3] Watson, T. L., and Taber, Stephen, The Virginia rutile deposits: U. S. Geol. Survey Bull. 430, pp. 200-213, 1910.

In the preparation of this paper the writer has drawn freely on all available publications relating to the individual areas described.

MODE OF OCCURRENCE.

Rutile is found in each of the major groups of rocks—igneous, metamorphic, and sedimentary. It occurs (1) as small prismatic forms and acicular hairlike bodies, chiefly as microscopic inclusions in the rock-forming silicate minerals; and (2) as separate formless grains and masses of variable size. The first mode of occurrence is common but nowhere of economic importance; the deposits of the second group are less widespread and constitute the source of the mineral in the few known localities from which it is obtained in commercially valuable quantities.

Rutile is formed as a constituent of (1) igneous rocks, (2) pegmatite dikes, (3) contact-metamorphic deposits, (4) veins, and (5) regionally metamorphosed rocks. Of these several occurrences Nos. 1 and 2, rarely 3 and 5, constitute important sources of rutile.

ROCK ASSOCIATIONS.

Rutile occurs in both plutonic and volcanic igneous rocks and has been observed in most of the principal types (acidic, basic, and intermediate in composition), but with very few exceptions the rocks contain it only as a very minor constituent. It is usually in grains and crystals of microscopic size, though in some places it is found in masses visible to the unaided eye.

Most of the known deposits of rutile that are of commercial importance are associated with gabbro (including anorthosite), chiefly as deposits formed by magmatic differentiation. The region of Amherst and Nelson counties in Virginia, the Bay St. Paul area in Quebec, Canada, and the Kragero area in southern Norway belong to this type. A second important type of rutile deposit is found in Amherst and Nelson counties, Va., in dikelike bodies of the ultrabasic igneous rock nelsonite,[1] which is composed chiefly of the minerals ilmenite and apatite but which in places has rutile as the dominant mineral.

Rutile has been found in most classes of metamorphic crystalline rocks, such as gneiss, schist, phyllite, quartzite, and granular limestone and dolomite. It occurs in simple and geniculated forms in quartz veins and stringers in the metamorphic crystalline rocks of the Piedmont province of the southern Appalachians. Rutile has been reported as an important constituent in parts of the apatite veins of Norway and Sweden, which, according to Vogt,[1] are pneumatolytic in character and connected with gabbro. In these veins the mineral is associated with the titanium minerals ilmenite and titanite, and is so abundant in some places as to be mined.

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[1] Watson, T. L., Mineral resources of Virginia, p. 300, 1907; Watson, T. L., and Taber, Stephen, U. S. Geol. Survey Bull. 430, pp. 206–207, 1910; Watson, T. L., and Taber, Stephen, Virginia Geol. Survey Bull. 3–A, pp. 100–155, 1913.

Rutile and ilmenite occur as primary constituents of pegmatite dikes[2] of granitic composition in Goochland and Hanover counties, Va., described on pages 401–404. The rutile is present in considerable quantity at this locality, and is of potential commercial value. Hess[3] has described the occurrence of rutile in association with minerals of the rare-earth metals in the pegmatite body at Baringer Hill, Llano County, Tex.

Because of its resistance to atmospheric agencies, rutile is a common mineral in beds of sand and gravel and in the residual material derived from the weathering of crystalline rocks in which it originally occurred. It is to be found in many gold-bearing sands and gravels, in the monazite sands of the Carolinas, and in similar sands composed of heavy resistant minerals at numerous other localities.

MINERAL ASSOCIATIONS.

The minerals associated with rutile include a wide range of species. As a product of crystallization from rock magmas, it is associated with most of the common rock-forming silicate minerals, including quartz. Where formed in metamorphic rocks by regional metamorphism, its associates, in addition to the common rock-forming silicate minerals, are usually a group of heavy minerals found in metamorphic rocks, such as kyanite, magnetite, and ilmenite. Where it occurs as a vein mineral, the commonest associate of rutile is of course quartz, but with these are other titanium minerals, especially ilmenite, and iron oxides. In some veins and pegmatites the associated minerals comprise some usually regarded as having been formed by pneumatolysis, such as those of the apatite veins of Norway, Sweden, and Canada. In alluvial and water-sorted sands rutile is associated with the heavy resistant minerals, such as ilmenite, magnetite, chromite, monazite, garnet, zircon, spinel, and locally gold.

DISTRIBUTION.

Rutile has a very broad distribution, but it is rarely found in large quantity and the known deposits of commercial value are few and are widely separated, being limited to three localities in North

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[1] Vogt, J. H. L., Genesis of ore deposits: Am. Inst. Min. Eng. Trans., p. 646, 1901.

[2] Hess, F. L., Min. World, vol. 33, pp. 35–37, 1910; Watson, T. L., and Taber, Stephen, Virginia Geol. Survey Bull. 3–A, pp. 252–253, 1913.

[3] Hess, F. L., U. S. Geol. Survey Bull. 340, pp. 287–294, 1908.

America and one each in Europe and Australia. The commercial localities include (1) the Amherst-Nelson and Hanover-Goochland areas in Virginia; (2) Bay St. Paul, in northern Quebec, Canada: (3) Kragero, in Norway; and (4) an area near Mount Crawford. 25 miles northeast of Adelaide, South Australia.

Each of these localities, except the Hanover-Goochland area, has produced some rutile, but the Amherst-Nelson area has yielded the largest quantity.

RUTILE IN THE EASTERN STATES.

The deposits of rutile in the eastern United States extend from New England to Alabama, but all except those of Virginia are of scientific interest only, as they are not known to be of commercial value. There is great variation over the region in the mode of occurrence of rutile, both as to kind of rock and as to mineral associations. Of most of the deposits very little can be said beyond the statement of location, for they have not been the subject of special study in the field, and knowledge of them is yet imperfect. The principal localities are indicated on the map forming figure 93.

NEW ENGLAND.

Rutile has been reported from one or more localities in each of the New England States except Rhode Island, but so far as known the mineral has nowhere been noted in commercial quantity. The occurrences in the different localities show marked differences in the associated rocks and minerals.

MIDDLE NORTHERN STATES.

Minor deposits of rutile have been reported in New Jersey and New York. Pennsylvania was a small producer of rutile prior to 1901, when exploitation of the Virginia deposits was begun.

The occurrence of rutile in Pennsylvania is limited, so far as known, to the central portion of Chester County, in the extreme southeastern part of the State. (See 1, fig. 93.) The mineral was picked up from plowed fields during cultivation and sold for collections and to the dental trade.[1] It was reported to be well crystallized, in comparatively large crystals, and very pure. Kunz[2] reports double geniculated twins of rutile forming complete circles found near Parkesburg, some of which weighed more than a pound. The State has produced only a few pounds of rutile since 1901.

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[1] Hess, F. L., U. S. Geol. Survey Mineral Resources, 1906, p. 530, 1907; idem, 1908, pt. 1, p. 744, 1909.

[2] Kunz, G. F., Gems and precious stones, p. 193, New York, 1890.

Prof. Florence Bascom,[1] who has completed the geologic mapping of Chester County, has kindly furnished the following statement:

The formations in which the rutile occurs are highly metamorphosed sediments. The chief deposits of the mineral in Chester County, and these can hardly be of commercial importance, are as follows: (*a*) It is weathered out from the Cambrian (Chickies) quartzite on slopes of the North Valley Hills in the

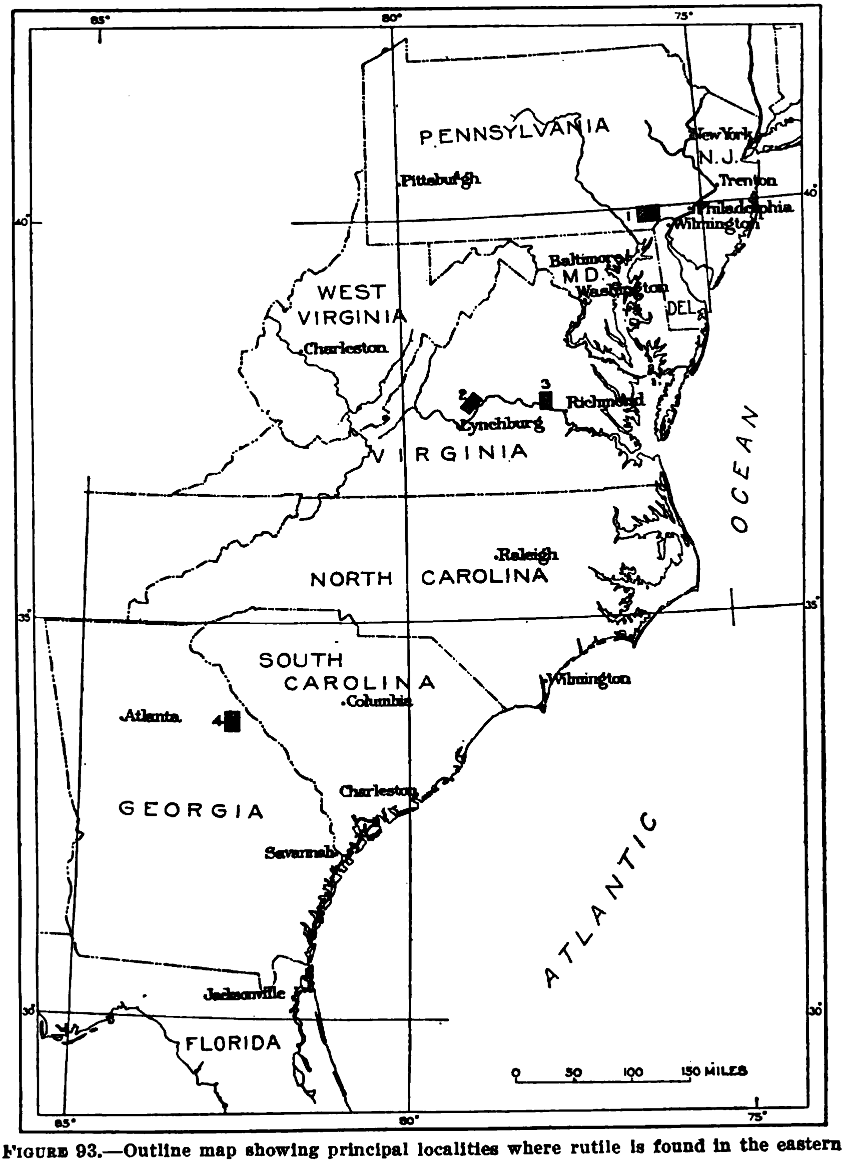

FIGURE 93.—Outline map showing principal localities where rutile is found in the eastern United States.

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[1] Personal communication.

neighborhood of Parkesburg and in railway cuts northeast of Pomeroy and west of Atglen. (*b*) Along the Valley road southeast of Coatesville it is weathered out from Cambrian and Ordovician (Shenandoah) limestone. Chester Valley and hills are parts of an overturned syncline of Paleozoic (Cambrian and Ordovician) sediments.[1] (*c*) Rutile occurs in Cambrian and Ordovician limestone in the Doe Run region, south of Coatesville and Chester Valley. This limestone lies on a folded thrust plane with pre-Cambrian gneiss above and below it. (*d*) It is found in similar limestone at the county poorhouse quarry in West Bradford, south of Chester Valley; also in East Bradford.

SOUTHEASTERN ATLANTIC STATES.

Rutile is found in most of the southeastern Atlantic States, but prior to the opening of the deposits in Nelson County, Va., in 1900, it was not known that the mineral occurred at any place within these States in sufficient quantity to be of commercial value, although rutile of gem grade had been found at a number of localities. Before 1900 the most noted rutile locality in the South was Graves Mountain, Ga., the production from which has been confined to cabinet specimens and a small quantity for the gem trade.

THE CAROLINAS.

Prior to 1906 a small production of rutile was reported from the Carolinas as a by-product obtained in washing sands for monazite, principally at Ellenboro, Rutherford County, N. C., and near Gaffney, Cherokee County, S. C. The workable deposits of monazite, containing some rutile in places, are confined largely to stream sands and gravels derived by weathering from granites, gneisses, and schists of the Carolina gneiss, which is mapped by the United States Geological Survey as Archean.

Rutile in various mineral associations has been reported from more than 20 counties in North Carolina, but so far as known it does not occur anywhere in large quantity. Many of the North Carolina localities, however, have furnished rutile of gem grade, and the State has probably yielded more rutilated quartz of unexcelled beauty for gems than all the other American localities combined.

Rutile occurs in South Carolina principally in the form of loose grains and crystals in the monazite sands near Gaffney, Cherokee County. Rutilated quartz is reported from the monazite belt and rutile crystals are found in the vicinity of Prosperity, Newberry County. Crystals which show some wear are found in Kershaw County.

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[1] See, on region to the east, U. S. Geol. Survey Geol. Atlas, Philadelphia folio (No. 162), 1909.

GEORGIA.[1]

Graves Mountain lies in the extreme western part of Lincoln County, Ga., within less than a mile of the Wilkes County boundary, 10 miles nearly east of Washington, the county seat of Wilkes County, and about 40 miles northwest of Augusta. (See 4, fig. 93, and fig. 94.) It is within the Piedmont Plateau province, near the eastern border, a short distance north of the fall line.

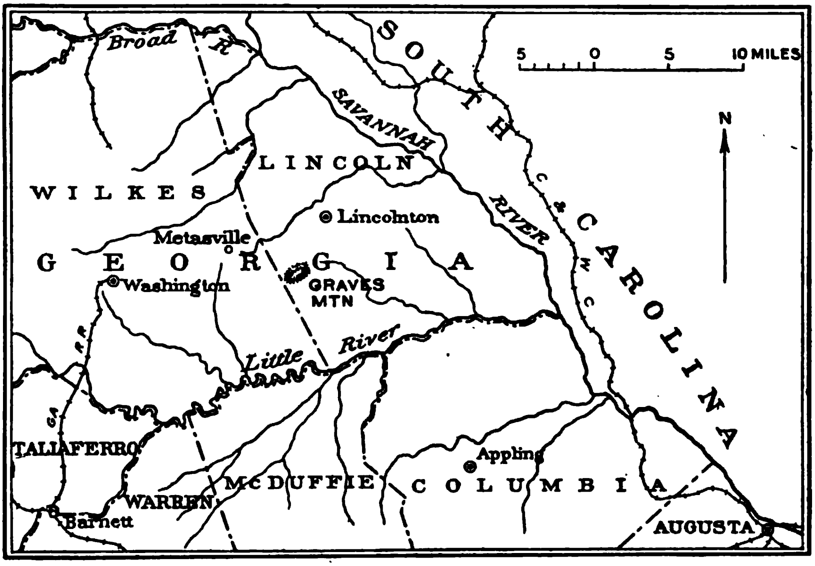

FIGURE 94.—Map showing location of Graves Mountain, Ga.

Graves Mountain, a conspicuous ridge (monadnock) of partly reduced hard rock, has an elevation of several hundred feet above the surrounding Piedmont Plain, is 2 miles in length along an approximate northeast line, and is less than half a mile wide. It is less steep on the northwest side, which corresponds with the direction of dip, and its upper portion is greatly roughened from weathering.

The rock composing the ridge is a fine-grained quartzite, which is in part schistose, rather thinly foliated, and in part essentially massive in structure. The hill also contains a kyanite-hematite rock. Igneous rocks have not been observed at Graves Mountain, but they occur at several localities in the vicinity. In the basal portion of the ridge and for some distance up the northwest slope the quartzite is crushed to a schist, containing considerable sericite and accessory kyanite, small grains of rutile, and black oxide of iron. A partial chemical analysis of the rock gave SiO_2, 79.18 per cent; Al_2O_3, 14.14 per cent; Fe_2O_3, 3.17 per cent. Microscopic study shows that rutile occurs in grains and crystals formed along the boundaries of the quartz grains and as inclusions in the quartz and kyanite.

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[1] Watson, T. L., and Watson, J. W., A contribution to the geology and mineralogy of Graves Mountain, Ga.: Virginia Univ. Philos. Soc. Bull., Sci. Sec., vol. 1, No. 7, pp. 201–221, 1912.

On the crest of the ridge and for an undetermined distance down the slopes the rock is a fine-grained quartzite, which has essentially the same composition as the quartzite schist. It is composed largely of fine sugary quartz but contains some muscovite and in places abundant kyanite that is pale green when fresh, crystals of blue lazulite, and small grains of red rutile. Pyrophyllite is rather common. Kyanite, lazulite, and rutile are as a rule intimately associated. The kyanite and lazulite are commonly embedded one in the other, and the rutile occurs as separate grains and as inclusions in the other minerals. A partial chemical analysis of the massive quartzite gave SiO_2, 69.74 per cent; Al_2O_3, 24.86 per cent; Fe_2O_3, 0.53 per cent.

On top of the ridge the quartzite is cut by quartz veins, some of the larger of which measure several feet in width. These are apparently barren, but smaller quartz veins only a few inches wide carry rutile and iron oxide.

The rutile of Graves Mountain was first described and worked by Prof. C. U. Shepard,[1] who obtained it from the central depression on top of the ridge and along the northwest slope. The openings are old and at the time of the writer's visit in 1911 were largely obscured from caving. No coarse rutile was observed, but the mineral was noted in every specimen collected, chiefly as microscopic inclusions in other minerals and as small crystals and grains visible to the naked eye.

Coarse rutile crystals from this locality found in many mineral collections in this country are lustrous black to reddish brown and red, with brilliant orange-red in thin sections. They vary in size, some being as much as 5 inches in length, and occur both as single and twin forms. Kunz reports that fine single crystals weighing 4 pounds have been found. The single crystals are usually of prismatic habit and commonly show pyramidal terminations. Careful examination of the dumps at the openings and on the northwest slope of the ridge from which the mineral was mined, and inspection of thin rock slices, which showed rutile in microscopic particles, clearly indicate that the large rutile crystals must have come from a heavy dark-colored rock, composed of an aggregate of long-bladed and coarsely columnar crystals of kyanite, massive granular hematite, and quartz. In many places the rock carries hematite in excess of kyanite; elsewhere kyanite may predominate.

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[1] Am. Jour. Sci., 2d ser., vol. 27, p. 36, 1859; idem, vol. 28, p. 141, 1859.

ALABAMA.

Very little is known of the occurrence of rutile in Alabama. It has been noted at several localities in the crystalline area, but in none is it of commercial importance. In 1874 the Alabama Geological Survey observed its occurrence in mica schist in close proximity to a pegmatite dike in Chilton County. Occurrences in pegmatite bodies cutting mica schist have been noted in Coosa and Randolph counties.[1]

VIRGINIA.[2]

Thus far commercial deposits of rutile in the United States are limited to Virginia, from which the entire domestic production has been derived since 1902. The mineral is found in considerable quantity and of excellent quality in two rather widely separated localities in the crystalline region of the State. These are the area in Amherst and Nelson counties (2, fig. 93), located near the northwest edge of the Piedmont Plateau, and the area in Goochland and Hanover counties (3, fig. 93), lying near the central-eastern margin of the same province. (See fig. 95.) The geology and mode of occurrence of rutile in the two areas show striking differences, as is indicated in the descriptions below. Thus far the production has been derived entirely from Nelson County.

AMHERST AND NELSON COUNTIES.

LOCATION AND TOPOGRAPHY.

The principal rutile area lies in the west-central part of Virginia and occupies the south-central and southwestern parts of Nelson County and the contiguous northeastern part of Amherst County. Much the larger part of the area and probably all that will prove of economic value lies in Nelson County, and all the developments thus far made are included in this county. The area lies along the northwestern margin of the Piedmont Plateau, in the foothills of the Blue Ridge and near the base of the main ridge, 5 to 7 miles from the main line of the Southern Railway. Arrington and Tye River are the two nearest railway stations.

As mapped by the Virginia Geological Survey, the belt of rutile-bearing rocks extends in a general northeasterly direction for about

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[1] Personal communication from Dr. Eugene A. Smith, State geologist.

[2] Abstracted from Watson, T. L., and Taber, Stephen, Geology of the titanium and apatite deposits of Virginia: Virginia Geol. Survey Bull. 3–A, 308 pp., 1913. See also U. S. Geol. Survey Bull. 430, pp. 200–213, 1910.

16 miles and has a maximum width not exceeding 2½ miles. (See fig. 96.) It forms an area of comparatively low relief, with an average elevation of about 800 feet. Elevations of 1,400 to 2,000 feet are reached immediately on the west, north, and northeast sides of the belt. The streams of this area drain toward the southeast into James River through Tye, Piney, and Buffalo rivers and their tributaries. The map (fig. 96) gives a general idea of the topography of the area.

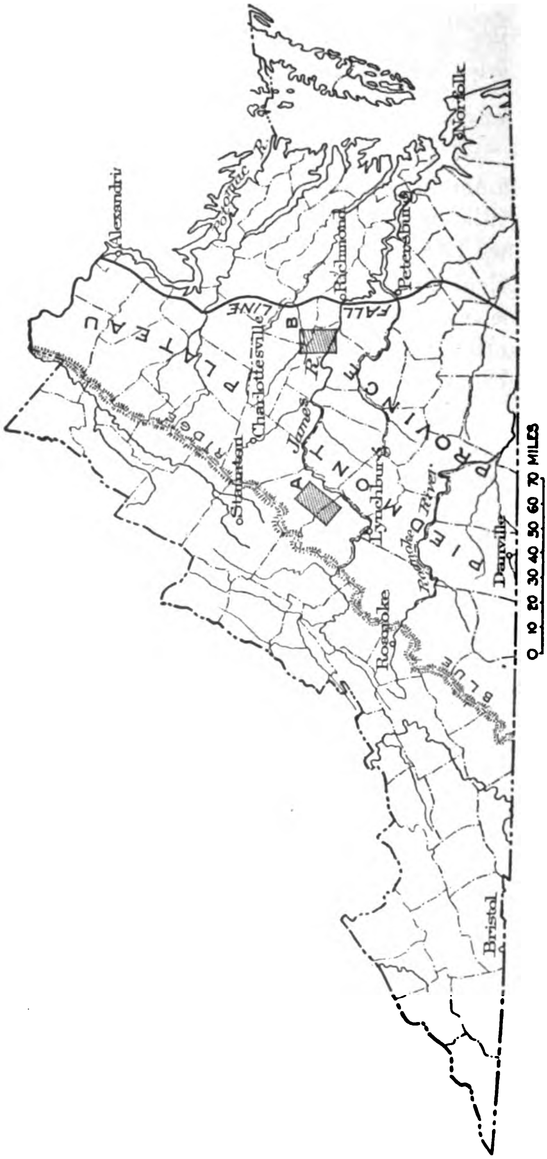

FIGURE 95.—Outline map of Virginia showing rutile districts. A, District in Amherst and Nelson counties; B, district in Goochland and Hanover counties.

GEOLOGY.

The rocks of the Amherst-Nelson rutile area are igneous in origin and show in their mineral and chemical composition derivation from a common parent magma. They are characterized by prominence of apatite and the titanium minerals ilmenite, rutile, and in a few

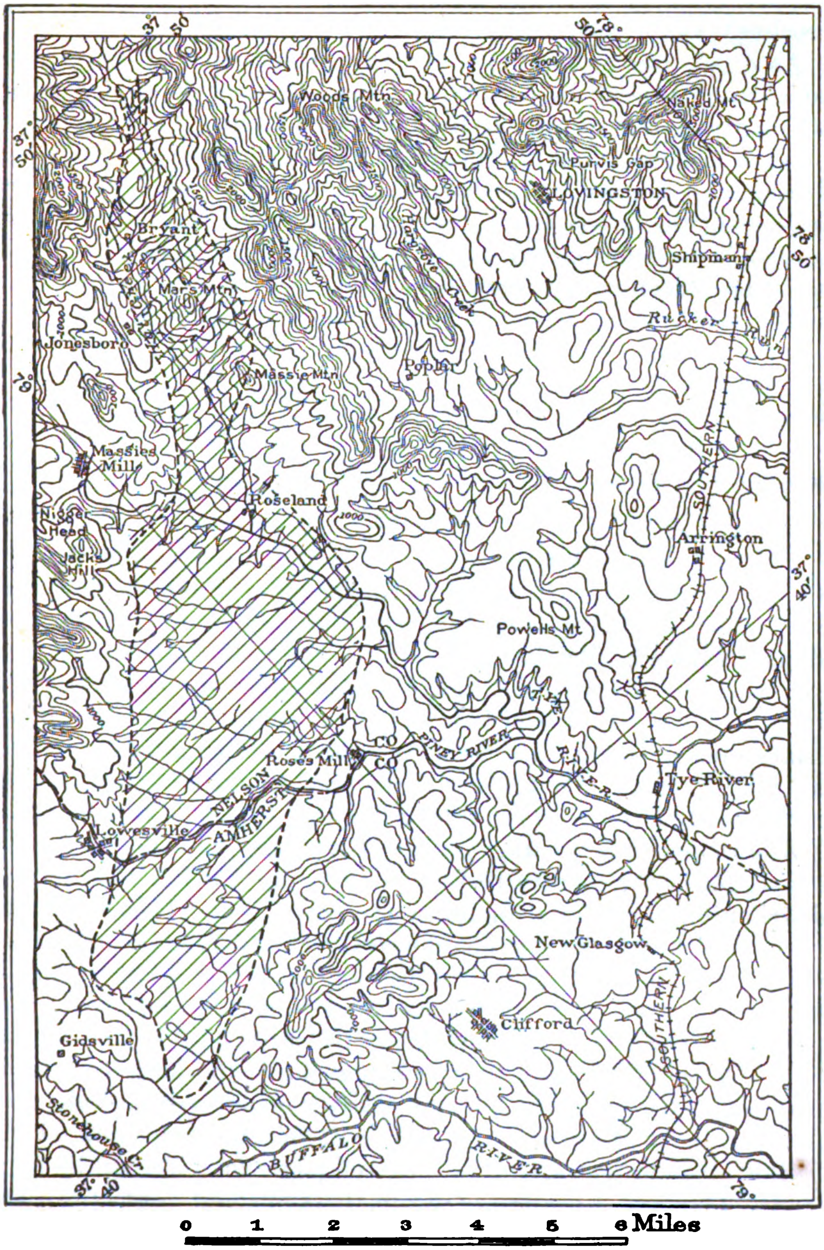

FIGURE 96.—Topographic map of the rutile area in Amherst and Nelson counties, Va. Ruling indicates area of rutile-bearing formation. Contour interval 100 feet.

places "titaniferous" magnetite; opalescent-blue quartz; pyroxene (hypersthene) or secondary hornblende derived from pyroxene as the dominant ferromagnesian mineral; and in most of the feldspar-bearing types by andesine, usually intergrown with orthoclase (microcline), as the dominant feldspar variety.

As a rule the rocks are considerably weathered and are covered to a variable depth by a mantle of their residual decayed product, which grades downward into the fresh hard rocks. They are mostly of even-grained texture, though in places porphyritic, and range from coarse grained in portions of the syenite to very fine grained in some of the nelsonite and diabase. They have been intensely but unequally metamorphosed, and in most of them complete or partial schistose structure has been developed. The effects of metamorphism are likewise shown in thin sections of the rocks under the microscope. The formation of secondary minerals from the original ones involved the production of hornblende from pyroxene, leucoxene from ilmenite and rutile, osteolite from apatite, and sericite from feldspar. Other alteration products noted in thin sections in some of the rocks are biotite, chlorite, epidote, and zoisite.

ROCK TYPES.

The principal rock types that have been mapped by the Virginia Geological Survey include (1) biotite-quartz monzonite gneiss with variant schists, (2) syenite, referred to as pegmatite in all publications previous to Bulletin 3–A of the Virginia Geological Survey, (3) gabbro, (4) nelsonite, and (5) diabase. Intermediate gradations are observed between most of these types, and usually the dominant minerals in one type form the subordinate or accessory minerals in the others. Of the five rock types enumerated, syenite and nelsonite are of most importance, as they are the rutile-bearing rocks.

Biotite-quartz monzonite gneiss.—The gneiss with accompanying schists forms the country rock of the deposits and has wide general distribution beyond the limits of the rutile area. It is a foliated gneiss which exhibits considerable textural and mineral variations, but the predominant phase is a medium dark-gray rock varying in texture from fine to medium coarse and from even grained to porphyritic. The principal minerals are the usual ones in this type of rock. A notable feature in its composition is the large content of plagioclase feldspar, and the two analyses made show that the rock is sodipotassic in composition. The chemical composition of the rock is given in the table of analyses on page 399. The gneiss is intruded in places by dikes of acidic (granite and pegmatite) and basic (diabase) rocks, and in places it contains segregations of diverse size and outline composed chiefly of biotite.

Syenite (*andesine anorthosite*).—Syenite is the most widespread and with reference to the occurrence of rutile the most important rock type in the rutile district. It occupies a narrow belt having a general northeasterly extension, the greatest breadth of which does not exceed 2½ miles and which covers an area of about 20 square miles. It is, as a rule, coarsely crystalline in texture and in places gneissoid or even schistose in structure. Along its southeast border, at the American Rutile Co.'s quarries, the rock exhibits abnormally coarse texture, and individual masses of hornblende, quartz, and feldspar measure several inches across.

The rock is composed chiefly of feldspar and blue quartz but contains also, in places near the margin, pyroxene (hypersthene, usually altered to hornblende), rutile, and lesser amounts of ilmenite and apatite. The ratio of these minerals varies greatly in different parts of the rock mass, but feldspar is the dominant mineral, except in portions of the border zone. Two facies of the rock mass which apparently grade into each other are recognized—a feldspathic variety, which includes the central and larger part of the rock mass, and for which the name piedmontose has been suggested; and a hornblendic variety, which is developed chiefly as a border zone and corresponds to tonalose. The central portion of the mass consists almost exclusively of feldspar, with only scattered grains of blue quartz and scarcely any visible rutile or other minerals. Rutile and in smaller quantity ilmenite are developed more abundantly along the southeast border of the mass, their occurrence being strikingly shown in the quarries of the American Rutile Co. on Tye River near Roseland. The general character and mode of occurrence of the rutile in this rock are described on pages 400–401.

The principal feldspar in the rock is a calcic soda variety (andesine) corresponding to about $Ab_{65}An_{35}$ and containing intergrowths of microcline oriented parallel to the twin lamellæ. In the feldspathic facies of the rock normative orthoclase (microcline) ranges from 16.68 to 23.35 per cent. Opalescent-blue quartz and hypersthene or its alteration product, hornblende, are the next most abundant silicate minerals.

Gabbro.—The principal exposures of gabbro occur near the contact with the outside gneiss, some of them forming irregular areas between the gneiss and syenite. On the American Rutile Co.'s property at Roseland the gabbro grades into the syenite. Gabbro also occurs as dikelike masses, cutting the syenite with sharp contacts in the Roseland district, and as dikes cutting gneiss in the Lovingston district.

The gabbros are light to dark gray rocks, generally of fairly even-grained texture, though in places porphyritic, and slightly to strongly schistose in structure, the latter phase yielding a uralitized gabbro gneiss. The principal minerals are feldspar (andesine) and pyroxene (hypersthene), partly or completely altered to hornblende. Subordinate ilmenite, rutile, and apatite occur, and pyrrhotite and graphite are generally present, the graphite occurring in considerable quantity in some localities. By increase of the ore minerals and decrease of the silicate minerals the gabbro passes through gabbro-nelsonite into nelsonite. The chemical composition of the gabbro is shown in the table of analyses on page 399.

Nelsonite.[1]—Nelsonite is the name given to a group of titanium and phosphorus bearing rocks of igneous origin, occurring in dikelike bodies of varying size and irregular shape in the rutile area of Amherst and Nelson counties and to a less extent farther southwest in Roanoke County, Va. The nelsonite bodies usually occur along the border portion of the syenite mass, and most of them are confined to the syenite area, but some are in the outside gneiss.

Nelsonites are holocrystalline, even-grained, dark rocks composed chiefly of apatite with ilmenite or rutile, or both, and in some places magnetite. Here and there it has a porphyritic texture, with apatite forming the phenocrysts. Subordinate silicate minerals may or may not occur, and pyrite (perhaps secondary) is an almost constant minor constituent. Variation in mineral composition gives rise to the varietal forms ilmenite nelsonite, rutile nelsonite, magnetite nelsonite, biotite nelsonite, hornblende nelsonite, and gabbro-nelsonite. Of these only the variety rutile nelsonite is of importance in the present discussion.

The rutile nelsonites show all gradations in the ratio of rutile and ilmenite, from those bodies composed of dominant rutile and apatite with little or no ilmenite to those composed of apatite and ilmenite with or without rutile. Gradations both vertically and laterally between these two extremes may be noted in the same body. Two analyses of rutile nelsonite are given in the table on page 399.

The bodies of rutile nelsonite are less widely distributed than the normal ilmenite nelsonite, being limited to the syenite area. They are found at several places southwest of Rose Union, on the Warwick tract, on the Bourne farm, and on the Giles tract half a mile northwest of Roseland. Each of these deposits has been prospected to a minor though unequal extent. The development work on the Giles tract has not been sufficient to reveal the size of the ore bodies, but that done on the Warwick farm by the General Electric Co. resulted in opening two dikes to a depth of 100 feet and for a distance of nearly 200 feet on the strike, while one of them was proved at the surface by pits and trenches for a distance of about 500 yards.

Though the nelsonite bodies are dikelike in general form the writer believes that they represent segregations in the igneous rocks inclosing them, being somewhat similar in mode of genesis to the well-known titaniferous magnetite ore bodies in gabbros and anorthosites.

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[1] Watson, T. L., Mineral resources of Virginia, pp. 300–302, 1907; Watson, T. L., and Taber, Stephen, Geology of the titanium and apatite deposits of Virginia: Virginia Geol. Survey Bull. 3–A, pp. 100–155, 1913.

Gabbro-nelsonites.—The type of rock termed gabbro-nelsonite, like nelsonite proper, is a new one. It occurs in dikes and is intermediate in mineral composition between normal gabbro and nelsonite. It is much less widespread in occurrence than either gabbro or nelsonite but has been especially noted along the eastern border of the syenite. It consists of silicate (hypersthene and secondary hornblende with variant feldspar) and nonsilicate (apatite, ilmenite, and magnetite) minerals in unequal amounts, the silicates predominating. In texture the rock is usually porphyritic, though here and there it is even grained. An analysis is given below. The name roselandose has been proposed for the rock.

Diabase.—The rocks grouped under the term diabase occur as dikes and range texturally from typical diabase to basalt. They are the youngest of the intruded rocks, as they may be found cutting all others in the area. The dikes vary in width from a fraction of an inch to more than 25 feet. They are confined chiefly to the rutile-bearing rocks of the syenite area but in places penetrate the surrounding gneiss. They present no unusual features in mineral composition. A chemical analysis of the typical specimen is given below.

CHEMICAL ANALYSES.

The composition of the various rock types briefly described above is shown in the following table:

Analyses of rocks from rutile area of Amherst and Nelson counties, Va.

[William M. Thornton, jr., analyst.]

	1	2	3	4	5	6	7	8	9
SiO_2	64.93	60.44	57.06	53.65	50.95	33.83	0.95	0.70	0.67
Al_2O_3	15.44	23.62	14.54	15.51	13.53	5.19	....	....	....
Fe_2O_3	1.94	.29	1.49	1.86	3.59	11.38	3.65	11.12	2.87
FeO	3.50	.19	4.52	8.33	9.67	15.06	7.95	27.93	5.04
MgO	1.22	.21	4.10	4.27	5.19	8.57	.25	.72	.15
CaO	3.43	5.59	4.37	6.26	8.99	8.22	11.13	8.34	12.16
Na_2O	3.08	4.94	3.13	3.06	2.53	1.28	....	....	....
K_2O	4.02	3.37	1.96	1.80	1.41	.50	....	....	....
H_2O-	.06	.08	.09	.11	.26	.45	.21	.15	.09
H_2O+	.78	.32	1.32	1.02	1.43	.75	.35	.58	.11
TiO_2	1.08	1.11	7.10	3.62	2.63	10.00	65.90	42.84	69.67
P_2O_5	.42	.15	.24	.75	.54	4.84	8.14	6.89	9.41
MnO	.06	Trace.	.04	.06	.09	.26	.26	.18	....
CO_2	Trace.	Trace.	.09	Trace.	Trace.	Trace.	Trace.	Trace.	....
S	Trace.	Trace.	Trace.	Trace.	.09	.25	1.61	....	.34
Cl	....	....	....	....	....	.04	None.	.01	Trace.
F	....	....	....	....	....	.55	.34	.21	.70
	99.96	100.31	100.05	100.30	100.90	101.39	100.74	99.67	101.21
Less O	....	....	....	....	....	.30	.54	.09	.39
						101.09	100.20	99.58	100.82

1. Average of two analyses of biotite-quartz monzonite gneiss.
2. Average of four analyses of feldspathic facies of syenite.
3. Average of three analyses of hornblendic facies of syenite.
4. Average of four analyses of gabbro.
5. Average of four analyses of diabase.
6. Analysis of gabbro-nelsonite.
7. Analysis of rutile nelsonite, Giles tract, near Roseland.
8. Analysis of ilmenite nelsonite, Shelton farm, 1 mile northwest of Roseland.
9. Analysis of rutile nelsonite, General Electric Co.'s mine, near Roses Mill.

WORKABLE DEPOSITS.

The general character and mode of occurrence of rutile in the Amherst and Nelson area have been fully described in previous publications,[1] especially in the State Survey report, to which the reader is referred. Two distinct types of rutile occur in the area and each has been mined. They are (1) syenite (formerly called pegmatite) rutile, in which the rutile occurs chiefly as disseminated grains of various sizes and as segregations in the form of wavy lines representing masses which have been modified by dynamic metamorphism in the coarse-grained syenite; and (2) nelsonite rutile, in which the rutile occurs as a constituent of a variety of the rock nelsonite having a dikelike character and composed normally of apatite and ilmenite.

In the first type rutile occurs as an original constituent irregularly distributed through the syenite, chiefly within the southeastern portion of the rock mass. The mineral ranges from sparsely disseminated grains to segregations, which locally may make up 30 per cent or more of the rock mass, with a probable average of 4 or 5 per cent for the quarries of the American Rutile Co. near Roseland.

The quarries of the American Rutile Co. are opened in both the feldspathic and the hornblendic facies of the syenite, each of which is quarried and milled for rutile. Ilmenite is associated with rutile in each facies of the rock but apparently is in larger amount in the hornblendic facies, and this is confirmed by the milling operations, which usually show for the same amount of material milled a much larger percentage of ilmenite in the hornblendic facies of the rock, locally known as black rock, than in the feldspathic facies or white rock. The ratio is variable, but in the hornblendic rock ilmenite may equal or even exceed the rutile. Locally apatite is associated with the rutile, especially in the larger segregations of rutile.

Analyses of rutile from Nelson County, Va

[William M. Thornton, jr., analyst.]

	Syenite rutile.	Nelsonite rutile.
TiO_2	95.71	98.80
FeO	2.35	1.68
SiO_2	.92	.26
Cr_2O_3	.02	.07
V_2O_3	.15	.20
	99.15	101.01
Specific gravity	4.196	4.21

Nelsonite rutile is limited in occurrence to the rutile variety of the rock nelsonite, the normal type of which is composed of ilmenite and apatite. The ratio of rutile and ilmenite in the rutile-bearing bodies varies, as is clearly shown in the percentages of the three principal minerals calculated from analyses of ilmenite-bearing rutile nelsonite and rutile-bearing ilmenite nelsonite:

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[1] Watson, T. L., and Taber, Stephen, U. S. Geol. Survey Bull. 430, pp. 200–213, 1910; Virginia Geol. Survey Bull. 3–A, pp. 193–197, 1913.

	Rutile.	Ilmenite.	Apatite.
Rutile nelsonite	64.56	9.73	22.18
Ilmenite nelsonite	5.76	60.65	29.57

The nelsonite rutile occurs in anhedral grains not exceeding, as a rule, 3 millimeters in size, although segregations of coarse rutile which grade into nelsonite are observed. The nelsonite rutile is uniformly darker in color than the syenite rutile.

The rutile mined in the Nelson County area at present is exclusively the syenite type quarried and milled by the American Rutile Co. at Roseland. Since the completion by this company of its concentrating mill at Roseland in 1902, a large total production of rutile has been made, which not only supplies the markets of this country but much of the European demand. Nelsonite rutile was formerly mined by the General Electric Co. on the Warwick tract near Roses Mill, but operations were discontinued in 1909, when, it is said, 100 tons of material containing 50 per cent TiO_2 was shipped to a Pennsylvania company for concentrating.

The production, price, and uses of rutile in Virginia, the only producing State in the United States, have been fully discussed in previous publications of the Federal and State surveys,[1] to which the reader is referred.

GOOCHLAND AND HANOVER COUNTIES.[2]

LOCATION AND TOPOGRAPHY.

The discovery of a second area of commercial deposits of rutile in Virginia was announced in 1910. The deposits are located near the central-eastern margin of the Piedmont province, in the northwest corner of Goochland County and the adjacent extreme southwestern part of Hanover County, 17 to 25 miles northwest of Richmond. (See fig. 95.) They lie near Peers, Waldelock, and Gouldin, between the main line of the Chesapeake & Ohio Railway on the north and the James River division of the same railway on the south, and may be reached from Beaver Dam station on the main line or from Maiden and Sabot on the James River division.

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[1] U. S. Geol. Survey Mineral Resources; Bull. 430, pp. 200–213, 1910; Virginia Geol. Survey Bull. 3–A, 308 pp., 1913.

[2] Hess, F. L., New rutile deposits near Richmond, Va.: Min. World, vol. 33, pp. 305–307, 1910.

Watson, T. L., and Taber, Stephen, Geology of the titanium and apatite deposits of Virginia: Virginia Geol. Survey Bull. 3–A, pp. 248–261, 1913.

Topographically (see fig. 97) the area forms a part of the moderately dissected eastern margin of the Piedmont province without marked elevations above the general area, which averages about 300 feet above sea level and is drained by South Anna and James rivers and their tributaries.

GEOLOGY.

The area is composed of crystalline metamorphic rocks in an advanced stage of decay. The moderately fresh rocks are covered by a mantle of decayed rock varying in thickness, and exposures of hard rock are rare except along stream courses. The country rock of the region comprises a granitic gneiss of variable composition, cut in many places by pegmatite dikes, and basic igneous rocks, including diorite, diabase, and pyroxenite. The gneiss contains much biotite and hornblende and the usual large amounts of feldspar and quartz, the proportion of which varies considerably. It is penetrated by numerous pegmatite dikes, which usually lie in the foliation planes and some of which are rutile-bearing.

The pegmatites range from several inches to 4 feet or more in width, are of granitic composition, and, like the inclosing rock (gneiss), have been mashed and are more or less highly schistose. They are very feldspathic and contain both potash and soda-lime feldspars, some quartz, and less mica (muscovite and biotite), and some of them contain rutile and ilmenite. Like the gneiss, the pegmatites are decomposed for a considerable depth below the surface. Rutile is an original constituent of the pegmatites and occurs in grains and masses that reach many pounds in weight.

WORKABLE DEPOSITS.

The rutile occurring in the several areas in Goochland and Hanover counties is of excellent grade and somewhat resembles in physical character that occurring in the syenite of Nelson County, but much of it is redder and brighter. It ranges in size from small grains to large masses. Hess mentions one mass found on the Nuckols farm that weighed 200 or 300 pounds.

The rutile is associated with some ilmenite, and a little apatite has been observed. Rutile occurs (1) as loose grains and masses on the surface and in the soil derived from the pegmatites through their disintegration and (2) as a constituent of the pegmatite dikes.

The several rutile areas have been prospected to a slight extent by pits and shafts, the deepest of which (not exceeding 75 feet) have hardly penetrated below the zone of rock decay. Prospecting has been confined chiefly to the Bowe farm, near Gouldin, in Hanover

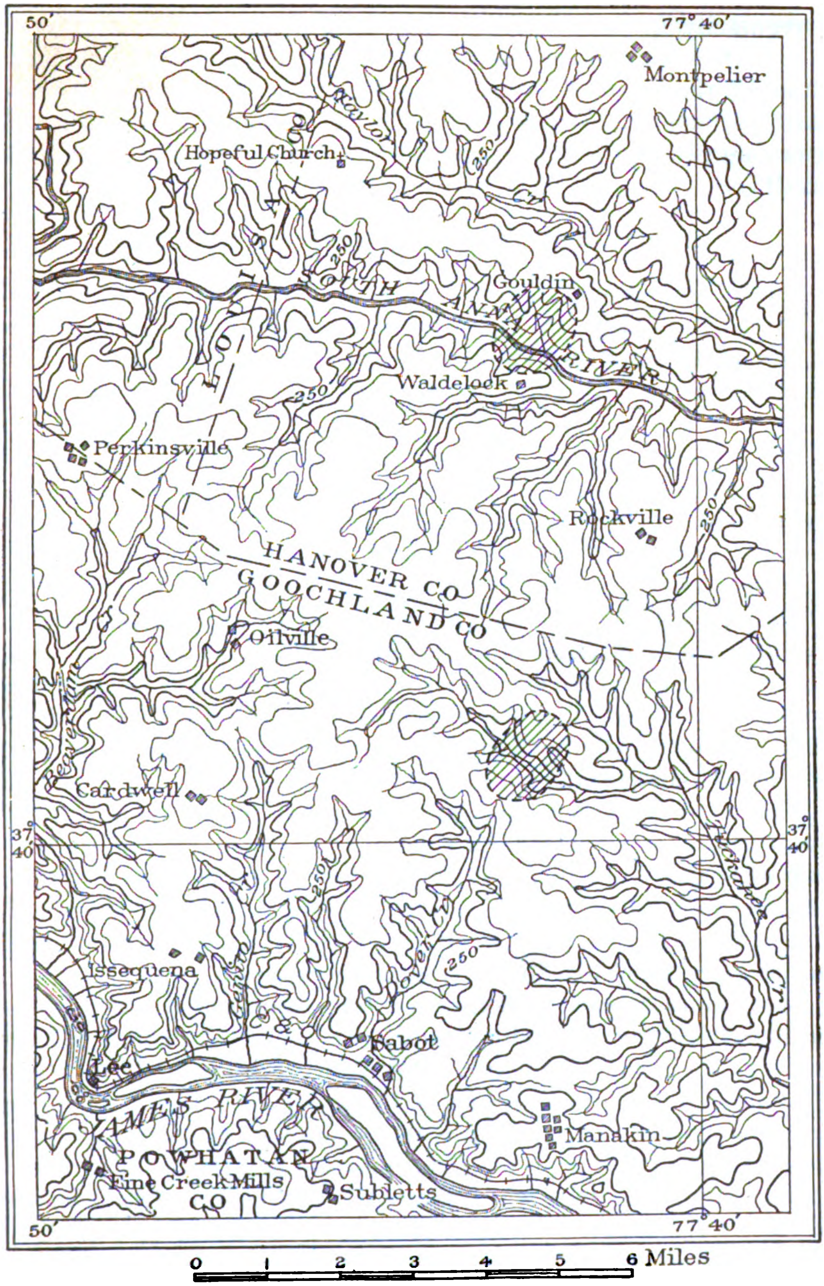

FIGURE 97.—Topographic map of the rutile areas in Goochland and Hanover counties, Va. Ruling indicates areas of rutile-bearing rocks. Contour interval 50 feet.

County, and the Nuckols farm, near Peers, in Goochland County. Irregularity in both quantity and distribution of the rutile in the pegmatite bodies is indicated by the results obtained. Large quantities of the mineral, ranging from fine sand to masses weighing many pounds, are found loose on the surface and in the soil over areas aggregating many acres, which could be worked at a relatively small cost.

SOME FOREIGN DEPOSITS OF RUTILE.

Rutile has been produced in recent years in Quebec, Canada; South Australia; and Kragero, Norway. The geology of these areas, so far as the writer has information, is separately discussed below.

ST. URBAIN, QUEBEC.

The principal known occurrence of rutile in Canada and the only one that has been productive is about 2 miles west of the village of St. Urbain, which is about 10 miles north of Bay St. Paul, on River Gouffre, and about 60 miles east of Quebec. It was first noted by T. Sterry Hunt, who briefly described it in 1863, but for the details of the geology of the rutile deposits at this locality we are indebted to the recent investigations of Charles H. Warren.[1]

The ilmenite-rutile deposits near St. Urbain, like many other occurrences of ilmenite, are contained in anorthosite, the feldspars of which are chiefly andesine. The rock is poor in femic minerals and locally shows some crushing.

The larger ilmenite bodies exhibit as a rule the form of elongated masses, some of which have dikelike outlines that conform in direction to an indistinct gneissoid structure in the anorthosite. The contacts between the ore bodies and the inclosing anorthosite are usually sharp, although gradation occurs in places. A narrow band of dark-brown mica is developed locally along the contacts.

Most of the ilmenite bodies are free from rutile, but rounded grains of feldspar (andesine), biotite, and spinel are noted as accessories in the rutile-free bodies. Quantitative estimates of the accessory minerals contained in one of the principal bodies show a general average of 5 to 6 per cent, with considerable portions containing not more than 2.5 per cent. The ilmenite may be massive, but it usually occurs in grains which range in size from 3 to 12 millimeters in cross section, with a probable average of 6 or 7 millimeters. Warren's study of polished surfaces shows that the individual grains of ilmenite are not homogeneous in composition, although identical in character, but are made up of very fine lamellar intergrowths of two kinds of material, and he states that the facts point to the conclusion that the material intergrown with ilmenite is hematite.

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[1] Warren, C. H., The ilmenite rocks near St. Urbain, Quebec; a new occurrence of rutile and sapphirine: Am. Jour. Sci., 4th ser., vol. 33, pp. 263–277, 1912.

A second and, so far as the present discussion is concerned, the most interesting as well as the commercially most important type of ilmenite body is a rutile and sapphirine bearing ilmenite which has been exposed for a length of about 300 feet, a width of 50 feet, and a maximum depth of 15 feet. Warren describes the deposit as follows:

> Its contacts with the anorthosite, where exposed, have a roughly east and west trend and are nearly vertical. In the ore are several streaks of anorthosite which have also a nearly vertical extension and a more or less marked schistosity following much the same direction. There is also in the ore in places a feebly marked banding with the same trend. Farther west and southwest of this deposit several small dikelike masses of ilmenite are exposed with the same orientation, but these carry no rutile, etc.
>
> The mineralogical character of the greater part of the ilmenite rock in this mass is essentially the same as that previously described. The grain, however, appears on the average to be a little finer. A portion of the deposit differs from the rest and from other known bodies of ilmenite associated with anorthosite rocks in containing a notable percentage of rutile and a smaller amount of the rare mineral sapphirine.
>
> The rutile-bearing portion was first observed as a streak 2 feet wide, with a nearly vertical dip and an indistinctly marked banding parallel to the walls, which ran east and west. The passage of this streak into the rutile-free ilmenite on both sides was very sudden. Toward the west the rutile-bearing portion widened and was somewhat less sharply defined, and there is evidence which points to the occurrence of rutile-bearing bands and patches. It appears, however, to always change quite sharply into the rutile-free rock. It was traced for several hundred feet.
>
> Cutting the ore body in the rutile-bearing portion is a streak of anorthosite rock which itself carries more or less rutile. The rutile makes up from 2 to 3 per cent of this rock, as nearly as it was possible to estimate it. It is associated with ilmenite and a considerable amount of biotite. These minerals are arranged along distinct lines of schistosity. No sapphirine has been noted in this rock.
>
> The rutile-bearing rock is of a brownish-black color and consists of a rather finely granular ilmenite thickly sprinkled with grains of an orange-red rutile, a smaller amount of feldspar, biotite, sapphirine, or their decomposition products, and spinel. The sapphirine can not be distinguished without the aid of a good lens, and then only upon very close inspection, about the feldspar and ilmenite grains in the form of very dark greenish-black grains. The less altered ore is firm, but weathered portions are somewhat friable. All of the material collected shows more or less limonite along cracks and joints. In a limited portion of the rutile-bearing rock fairly numerous plagioclase grains or groups of grains, often larger than the average in size, are present. These feldspars sometimes reach a length of 2 or 3 centimeters and 1 centimeter in width and are characteristically associated with a strong development of biotite plates.
>
> Microscopic thin sections of the rutile-bearing rock disclose a highly xenomorphic texture for all of the constituent minerals with the one exception of the spinel inclusions in some of the feldspar grains. The ilmenite forms an almost continuous background in which the other minerals lie. Its grains,

although irregular in outline, are roughly equidimensional and are fairly uniform in size, their average cross section being about 3 millimeters. They consist of the same lamellar intergrowths as previously described, but the two sets of lamellæ are narrower than in the former case, conforming to the smaller average size of the grains. The rutile is in the form of simple crystal grains or clusters of such and is of a beautiful orange or golden-brown color with a barely perceptible pleochroism. The cleavages are prominently developed. Twinning is rare. Individual grains attain a diameter of 3.5 millimeters. From this size they run down to mere specks, the average being in the neighborhood of 0.6 millimeter. It is distributed quite uniformly through the ilmenite and occurs also with the other minerals, being sometimes inclosed in their grains. The spinel is rather sparingly present and forms grains comparable in size to those of the rutile. In the feldspar-rich portions of the rutile-bearing rock it also occurs included in the feldspars in the form of exceedingly minute crystals. These inclusions deserve a brief description. Many of the feldspars are crowded with them. They are of a pale dull-green color and as a rule are definitely oriented with reference to the inclosing crystal. Just what the orientation is has not been made out. Many of the spinels have a highly perfect octahedral habit, the whole crystal coming into view with slight changes of focus. Other crystals show the characteristic cross sections of distorted octahedrons or form flat triangular plates. These attain a diameter of 0.015 millimeter, though usually smaller. Again, the spinels have the habit of relatively greatly elongated rods or somewhat flattened blades arranged in lines across the feldspars. The inclusions are isotropic, although, being wholly inclosed in the feldspar, which often exhibits a slight disturbance in its optical properties about the inclusions, they often seem to be slightly doubly refracting themselves. Minute inclusions of sapphirine have also been noted occasionally associated with the spinels, but these have a different color and are irregular in outline.

The feldspars are an andesine like that of the anorthosite. They are as a rule quite evenly distributed and of fairly uniform size comparable with the ilmenite, but occasionally, as noted, they become more numerous and of larger size and form groups of grains. Many of them show evidences of strains and slight bending. In even the fresher material collected the feldspar is usually partly replaced by secondary products, particularly where biotite and sapphirine were present with it, and in more highly altered specimens it is entirely gone.

The biotite is sometimes quite abundant and has the same characteristics as previously described. It is most intimately associated with the plagioclase, and where sapphirine is present it appears to have developed later than this mineral. Its position about the margins of the feldspar or replacing part of it is here, as elsewhere, strongly suggestive of a later secondary origin. Its alteration is to chloritic products.

An occasional grain of apatite has been noted, but it is hardly present as more than a trace.

The sapphirine, which is of especial interest here, it being not only a new occurrence of this rare mineral but also in a new association, seems to be confined to portions of the ilmenite rock which carry rutile. Even when alteration has destroyed both plagioclase and sapphirine, the characteristic alteration products enable it to be seen that the sapphirine has been quite a constant associate of the feldspar in the rutile-bearing portion. That there is some intimate relation between the feldspar and the sapphirine is shown by the fact that the latter generally lies between the feldspar and the ilmenite. It is often seen as a narrow band extending around the feldspar. The band may widen out into a larger mass. Again the feldspar may be surrounded by sapphirine of nearly or quite equal area. About a single feldspar grain the sapphirine usually has, throughout the greater portion of its extent, a uniform orientation. The mineral also includes ilmenite and rutile grains, and in one instance at least has been noted in contact with spinel. Where the feldspar is more abundant the sapphirine is also more strongly developed, and its grains have in some instances fairly continuous distribution through the section, and often lie, with and without included ilmenite and rutile, between the feldspar crystals, or even included in them. In such sections as much as 20 per cent has been observed, with about an equal amount of feldspar and rutile, a little spinel, and the remainder ilmenite. Here the larger grains frequently attain a diameter of 3 millimeters, the average being somewhat smaller (0.4 or 0.7 millimeter). Quantitative estimates of the amount present indicate something like 3 to 5 per cent for the general run of the rutile-bearing rock.

Warren made two quantitative estimates, by the Rosiwal method, of the mineral composition of the rutile-bearing rock in thin sections—one from a rutile-rich sample, the other from a rutile-poor sample—with the following results:

Mineral composition of rutile and sapphirine bearing ilmenite from St. Urbain, Quebec.

Rutile	20.4	11.3
Ilmenite-hematite	73.2	84.5
Sapphirine	3.2	.7
Undetermined	3.2	3.2

A chemical analysis of a sample of the rutile-rich type yielded the following result:

Analysis of rutile and sapphirine bearing ilmenite from St. Urbain, Quebec.

[R. S. Anderson, analyst.]

SiO_2	2.24
TiO_2	53.35
Al_2O_3	1.65
Fe_2O_3	13.61
FeO	24.49
MnO	.30
MgO	4.04
CaO	.30
	99.98

The rutile-bearing rock is regarded as a magmatic differentiation product in which there was an excess of titanic oxide and a smaller excess of magnesia and alumina. It represents an extreme and new ultrabasic type of igneous rock, for which Warren has proposed the name urbainite. No attempt has been made to classify it in the quantitative system, but it falls into a new position in the perfemane class (V), possibly close to the rutile nelsonites of Nelson County, Va.

Late in the seventies an English company mined a few thousand tons of the ilmenite for iron. In 1910 the deposits were leased and worked by the General Electric Co. for rutile, and it is said that a considerable quantity of the material was mined from an open cut and shipped to Schenectady, N. Y. The property has not been operated since 1910.

SOUTH AUSTRALIA.[1]

The known occurrences of rutile in South Australia are near Mount Crawford, in sec. 119, hundred of Para Wirra, and secs. 6 and 9, hundred of Talunga, 6 miles north of Blumberg, about 25 miles northeast of Adelaide, and 16 miles from Gawler station. Practically nothing has been published on the geology of these occurrences.

Gee[2] has made the following brief statement in regard to the occurrence of rutile in secs. 8 and 9, hundred of Talunga, 6 miles north of Blumberg:

> From time to time for many years past work has been carried on by various parties, but apparently in no instance has there been much enterprise or energy. The workings, which continue for about 150 yards in length, are principally a number of small shafts, cross trenches, and surface openings, from 3 feet to 30 feet in depth, disclosing a soft clay kaolinized dike formation, from 10 feet to 12 feet wide, striking slightly east of south. Through this material rutile crystals in various forms, both coarse and fine, can be seen, in some places dispersed throughout the matrix, in others in pockets and seams, and can be extracted by dishwashing. For some distance on each side of the formation fine rutile can be obtained on the surface, but the most valuable is in a small seam of gravel resting on a clay bed about 12 inches below the surface, and which yielded very good prospects indeed, much better than had been anticipated, judging from the débris on the surface and its position not being on the line. The better-class material is at each end of the workings. From each of those several samples were taken, also from the surface and shallow pits, which, when bulked, gave an average return of 1¼ per cent.

Hand specimens of the material obtained by Frank L. Hess, of the United States Geological Survey, from the leases of Francis J. Spence, have been studied by the writer, and the important features are summarized below. The specimens show chiefly a granular mixture of dark-red rutile and light-colored silicate minerals, mainly sericite, sillimanite, feldspar, and quartz. Pressure effects are visible in fractures in the rutile and quartz and in the orientation of the shreds of sericite that extend inward from the outer laminæ of the rutile. The marginal portions of the specimens show interleaving of rutile with mica.

A thin section examined under the microscope shows formless grains of deep-red rutile having slight pleochroism, good cleavage, and in most cases twinning. Inclusions of a black, opaque metallic mineral, probably ilmenite, occur in the rutile. The rutile grains are broken by fractures, along which there is some alteration to leucoxene. Small grains of quartz occur, and here and there shreds of colorless mica (sericite) are disseminated through the rutile or fill fractures, in which the sericite is probably of secondary origin.

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[1] Watson, T. L., and Taber, Stephen, Virginia Geol. Survey Bull. 3-A, pp. 35-37, 1913.

[2] Gee, L. C., Record of the mines of South Australia, 4th ed., pp. 356-357, 1908.

A second specimen showed rutile associated with much sillimanite in feltlike aggregates, less quartz, and little sericite. The specimen is considerably mashed. Microscopic study of a thin section cut from this specimen shows the chief mineral constituent to be rutile, which is accompanied by sillimanite, quartz, and feldspar (mostly plagioclase), together with accessory minerals as inclusions in the quartz and feldspar. The rutile is red to red-brown in color. It exhibits cleavage and, in places, twinning, and some particles show appreciable pleochroism. It occurs chiefly in granular masses and in aggregates of granules and microscopic crystals having good outward crystal form. It is free from inclusions but contains inclosures of the silicate minerals, especially quartz. Much sillimanite occurs in aggregates of fibers, showing a partial radiate arrangement and penetrating the quartz and feldspar. Pressure effects are evident in broken fibers of sillimanite, fractured rutile and quartz, and slight optical disturbance and partial granulation of the quartz.

In the mineralogic collections of the University of Virginia are several specimens of rutile labeled Blumberg, South Australia, which are similar in associations and general character to the specimens described above. These specimens also show marked evidence of mashing. One of them is composed chiefly of kaolinized feldspar with greenish scales of sericite and large and small grains of red rutile, more or less segregated as very minute stringers that lie for the most part in the foliation of the rock.

The mode of occurrence of the South Australia rutile is unknown, but from the brief statement of Gee as to the field relations and from the results of the writer's examination of hand specimens and thin sections it seems probable that the rutile occurs in pegmatite.

KRAGERO, NORWAY.[1]

Rutile has been noted at a number of localities in Norway,[2] but the deposit of greatest commercial importance is in the neighborhood of Kragero, on the southeast coast.

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[1] Watson, T. L., Kragerite, a rutile-bearing rock from Krageroe, Norway: Am. Jour. Sci., 4th ser., vol. 34, pp. 509–514, 1912.

[2] Vogt, J. H. L., Problems in the geology of ore deposits: Am. Inst. Min. Eng. Trans., vol. 30, pp. 646–647, 1901; see also references to Vogt's work in Zeitschr. prakt. Geologie, 1894–1897. Brögger, W. C., and Reusch, H. H., Verkommen des Apatit in Norwegen: Deutsche geol. Gesell. Zeitschr., vol. 27, pp. 646–702, 1875.

According to Vogt rutile occurs in the apatite veins of Norway and northern Sweden in sufficient quantity at numerous places to be profitably mined. The veins are connected with gabbro and were formed soon after the intrusion of the rock, which shows characteristic pneumatolytic action. Chlorine is present in the vein minerals scapolite and chlorapatite, and, besides rutile, the veins contain the titanium minerals ilmenite and titanite. Many of the veins carry some pyrite and exceptionally a little tourmaline.

According to Brögger,[1] the occurrence of rutile in the neighborhood of Kragero is confined to a large aplite dike situated 200 to 300 meters from the sea and about 100 meters above sea level. The rock is called a rutile aplite and is an even-granular white rock practically free from dark silicate minerals. Brögger says that the middle part of the dike contains rutile uniformly distributed through the rock in grains 0.5 to 2 millimeters in size and estimated roughly to amount to about 5 to 10 per cent by weight.

A second, and commercially the most important, occurrence of rutile in the aplite is referred to as schlieren of local enrichments of the mineral. Most of the schlieren consist almost exclusively of rutile, and these portions of the rock crumble easily to a grainy rutile powder. The rutile schlieren are unequally distributed through the dike, the richest ones being concentrated in a few zones, the largest of which is situated about in the middle of the dike.

In 1904 Brögger discussed the rock as a new member of the aplite series and named it kragerite. Concerning this rock Vogt[2] says:

> Brögger discussed a new rock, kragerite, a new member of the aplite series. The rock is of practical interest on account of its content of rutile. In theoretic connection the speaker considered this rock, which consists almost exclusively of albite and rutile, as a differentiation product of a gabbro magma, analogous to the appearance of lestiwarite, an aplitic differentiation product of a nepheline syenite magma, etc. In addition, mention was made, by analogy, of routivarite, anorthosite, and oligoclasite. The content of titanic acid in the kragerite was attributed to pneumatolytic processes during formation.

In a personal communication to the writer Vogt states that the rock has been found only at a single place in the neighborhood of Kragero and has small areal extent. It has been worked in later years for rutile, the percentage of which is variable.

The rutile-bearing rock, when submitted to analysis, is found to be medium grained, of light color, and granitic texture. Its most prominent megascopic constituents are light-gray and pinkish feldspars and much black rutile, with a little quartz. Several small areas of a green ferromagnesian mineral, probably pyroxene, partly altered and associated with rutile, were noted. The feldspar and quartz grains measure 1 to 2 millimeters in thickness; few of the rutile grains are more than 1 millimeter and many of them are less than 0.5 millimeter thick. Under the pocket lens most of the feldspar shows fine albitic twinning on cleavage surfaces. The rutile is partly disseminated as small grains through the rock, but most of it appears to be segregated along roughly parallel lines, suggesting the appearance of imperfect foliation, which Brögger refers to schlieren of local enrichments of the mineral.

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[1] The statements which follow have been taken partly from a report made by W. C. Brögger, Oct. 5, 1904.

[2] Vogt, J. H. L., Vidensk.-Selsk. Christiania Forh., Oversigt over Videnskabs-Selskabets Møder i 1904, p. 30, 1905.

A thin section of the less rich rutile-bearing portion of the rock was examined under the microscope and found to consist essentially of feldspar, much rutile, some quartz, and a little ilmenite. No mafic minerals were observed. Feldspar is the most abundant constituent and is composed chiefly of a soda plagioclase (albite-oligoclase), together with some microcline and orthoclase, the latter intergrown with a second feldspar (albite) as microperthite. Some of the feldspar anhedra show partial micropoikilitic structure developed from inclosures of other feldspar, quartz, and rutile. The feldspars are generally fresh, though here and there small areas of colorless mica due to alteration occur. The feldspar and quartz show some granulation about the borders, and a slight bending of the lamellæ of several plagioclase individuals was noted.

When calculated in the usual way from the chemical analysis of the rock (given below) the composition of the feldspar content is as follows:

Composition of feldspar in rutile-bearing rock from Kragero, Norway.

Orthoclase	6.12
Albite	52.40
Anorthite	5.56
Ab_nAn_m ratio	9.4:1
Orthoclase-Ab_nAn_m ratio	1:9.5
Total plagioclase	57.96
Total feldspar	64.08

Rutile, the next most abundant mineral to feldspar, occurs in forms ranging from irregular massive grains to small idiomorphic crystals. Some of the larger grains show partial crystal outline. It is deep red-brown and distinctly pleochroic, and much of it shows cleavage and twinning. Some ilmenite is associated with the rutile and in part exhibits slight alteration to leucoxene. The rutile occurs entirely enveloped by feldspar or along the sutures of feldspar individuals and of feldspar and quartz and penetrates for a greater or less distance into their substance. The relations of the rutile to the rock minerals suggest that it crystallized from the magma, like the feldspar and quartz, in the usual order of crystallization.

A thin section of the rutile-rich portion of the rock, representing probably the schlieren of Brögger, was studied microscopically. It is composed essentially of rutile, together with biotite partly altered to chlorite, some anhedral grains of apatite, and an altered light-colored silicate mineral, probably a potash feldspar.

In reflected light the rutile is dark brown to gray with faint greenish tinge; in transmitted light it is pleochroic, usually shows good cleavage and twinning, is marked by irregular fractures, and shows some alteration to leucoxene peripherally and along fractures.

Biotite, partly altered to chlorite, is developed in aggregates of shreds having in places a radial arrangement or grouping. Inclosures of the silicate minerals, chiefly biotite, are noted in the rutile, and rutile granules are distributed through the silicate minerals—a relation which apparently indicates contemporaneous crystallization of the rutile and silicate minerals.

An analysis of the rutile separated from the rock and freed as nearly as possible of silicate minerals yielded the following results:

Analysis of kragerite rutile from Kragero, Norway.

[William M. Thornton, jr., analyst.]

TiO_2	97.68
SiO_2	1.06
FeO	.81
Cr_2O_3	.39
V_2O_3	.55
	100.49

Specific gravity (determined by J. W. Watson), 4.225.

The rock was analyzed in the laboratories of the University of Virginia, with the following result:

Analysis of kragerite (rutile aplite) from Kragero, Norway.

[J. W. Watson, analyst.]

SiO_2	50.52
Al_2O_3	13.98
Fe_2O_3	.49
FeO	.16
MgO	.34
CaO	1.05
Na_2O	6.18
K_2O	1.00
H_2O-	.20
H_2O+	.30
TiO_2	25.00
P_2O_5	Trace.
V_2O_3	Not determined.
MnO	None.
CO_2	None.
S	.12
	99.34

580-P

PUBLICATIONS BY SURVEY AUTHORS ON METALS AND NONMETALS EXCEPT FUELS.

Compiled by Isabel P. Evans.

This bibliography is a revision, enlargement, and continuation to date of the bibliographic lists on metals and nonmetals except fuels previously published by the United States Geological Survey. It is compiled mainly from publications of the Survey, but cites also articles by Survey authors which have appeared in other publications. Articles that treat of several metals or nonmetals or use other combinations of them than those in the subject headings are placed under "General," and some of them are repeated in the lists relating to particular deposits.

The Survey publications, except those to which a price is affixed, may be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications, except the folios of the Geologic Atlas, which can be obtained only from the Director, may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.; the monographs from either the Director or the Superintendent of Documents. The publications marked "Exhausted" are not available for distribution, but may be seen at the larger libraries of the country.

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URANIUM. See Carnotite, etc.

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ZIRCON. See Monazite.

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